# 14 Separations and Waste Management

Separations and waste were managed under the same department until the late 1970s, when a separate Waste Management department was created. Separations functions involved refining products from the reactors to meet customer specifications, while waste functions dealt with the treatment of the residue materials. Separations involved two primary operations: liquid extraction and gas extraction. Liquid extraction—used to purify plutonium, uranium, and various other elements—was housed within the enormous canyon buildings, one in the F Area and one in the H Area. In addition to the main processing facilities were the A- and B-Lines, where concentrated liquids were converted to solid forms. Gas extraction—for tritium purification—originally took place in F Area, then in H Area. By 1960, major modifications had greatly altered nearly all separations work.

Separations Process Systems. The purpose of separations was, as the term implies, to separate useful products from waste. Initially, separations activities included the storage of waste as well. This simplified diagram shows the major activities of liquid separations and waste processing. Source: *Waste Management Operations*, Document ERDA-1537 (Aiken, South Carolina: Savannah River Plant, September 1977), II-23.
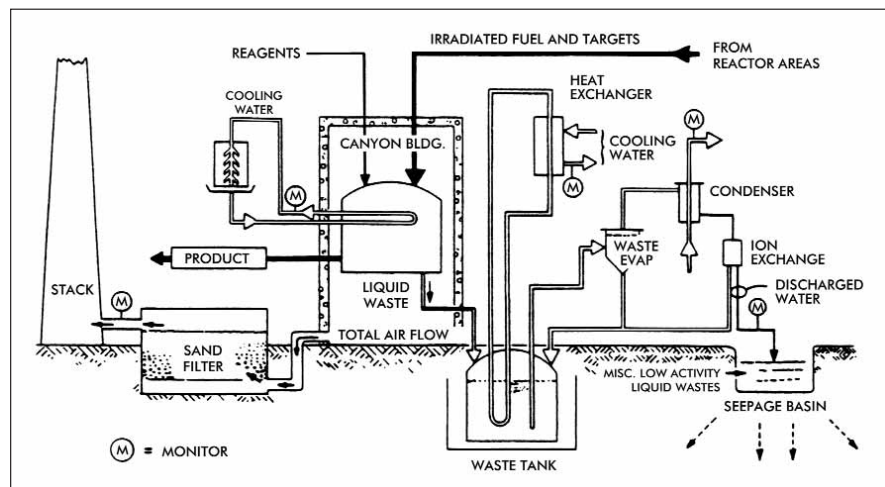
THE PROBLEM OF PLUTONIUM PURIFICATION

Initial research into the separation of irradiated plutonium from uranium and fission products was headed by Glenn Seaborg at the University of Chicago's Metallurgical Laboratory during the Manhattan project. Seaborg's group developed a process for sepa-

rating plutonium by using lanthanum fluoride to bind with and precipitate the new element. Seaborg and his group also investigated ion exchange and solvent extraction, both of which were important at Savannah River.[1]

Research at the Oak Ridge separations pilot plant and laboratories incorporated Du Pont chemists' experience and coordinated findings with Hanford and Los Alamos personnel. The work at Oak Ridge showed that bismuth phosphate was better suited to separation of plutonium from fission products, but that lanthanum fluoride was better suited to final concentration of the plutonium preparatory to conversion into metal. Problems with the bismuth phosphate process were that it did not recover uranium, which remained mixed with the process waste, and that it was slow. Although not ideal, the process was adequate for the emergency needs of wartime production, so it became the basis for the separations facilities at Hanford. However, what was suitable to meet war needs was less than ideal for the long term.[1]

Solvent extraction, as opposed to precipitation, is generally a much more efficient means of separation, and postwar investigations concentrated on this type of processing. The basic principle of solvent extraction is that certain solutions are immiscible—if mixed together then allowed to settle, the solutions will tend to separate into heavier and lighter layers, or phases. The chemistry of the phases can be adjusted so that select elements or molecules stay with one or the other phase when they separate. The process can also be operated continuously rather than in batches, as was done with precipitation. A solvent-extraction process that would separate both uranium and plutonium from fission products was developed at Argonne National Laboratory shortly after World War II. The process used an organic solution called hexone (methyl isobutyl ketone), and it was called Redox, for Reduction Oxide process. Pilot-scale development took place at Oak Ridge between 1945 and 1951, and operation of a full-scale Redox plant began at Hanford in 1952.[2]

Research toward the next improvement began in 1948 and was initially developed through about 1952. Called Purex,[3] the new process was better able to recover uranium than Redox, was more versatile, decreased fire hazards by incorporating less flammable solutions, lowered operating costs, and perhaps most importantly, reduced the amount of waste created.[4] The most important chemical in the Purex process was a compound (an organic solvent) called tri-n-butyl phosphate, also known as TBP.[5] The quality that made TBP of value was its ability to latch onto and release plutonium, uranium, and other elements with great selectivity. As related to nuclear materials processing, Purex generally referred to a countercurrent (two streams flowing in opposite directions) solvent-extraction process by which uranium and plutonium in a nitric acid phase were separated from other fission products

Genesis of the Idea

The initial concept of using TBP for plutonium separations can be attributed to Ray Fisher, who worked at Iowa State University's Ames Laboratory. In the mid- to late-1940s, Fisher attended a conference in Chicago that Warren Eister, an engineer in the Oak Ridge Chemical Technology Division, also attended. In 1992, Eister recalled a conversation the two had at the conference:

> After trying to impress Ray with our contributions to the Redox process… Fisher asked why we hadn't used tributyl phosphate (TBP) for the solvent instead of the hexone… since TBP was stable in nitric acid…. Our Chem Tech forces were devoted to Redox/hexone systems, and it was several years before TBP was seriously considered both for the recovery of uranium from the bismuth phosphate waste and for application at both Savannah River and Hanford for plutonium recovery.

Post-World War II efforts to improve plutonium purification involved, directly and indirectly, thousands of research personnel within a nationwide network of research facilities; it would thus be presumptuous to attribute the origin of a concept to a single individual or even a small group of researchers in such an environment. Charles Runion, Thomas Ellison, and Bill Lanham are noted to have been listed on the original patent for the process. Other persons may have also considered using TBP in speculative conversations. Although it may be that a conversation between Fisher and Eister marks the initial concept formation, credit for the idea should be shared between these persons and the many other scientists like them who collectively undertook the research and development efforts at the national laboratories and contractor facilities that turned the process into the important nuclear-materials processing technology used around the world today.

Source: R. L. Jolley, R. K. Genung, L. E. McNeese, and John E. Mrochek, compilers, *The ORNL Chemical Technology Division, 1950–1994* (Oak Ridge, Tennessee: Oak Ridge National Laboratory, October, 1994), 2–8.

and impurities by using TBP in an organic phase. The term could also be used to refer to operations that use these same chemical compounds to recover other materials, principally actinides.[6]

(Right) Savannah River Laboratory's Semiworks called TNX, 1951. Courtesy of SRS Archives, negative 6-157.

(Below) Mixer-settlers installed at Savannah River's TNX facility in 1960. Courtesy of SRS Archives, negative 6554-21.
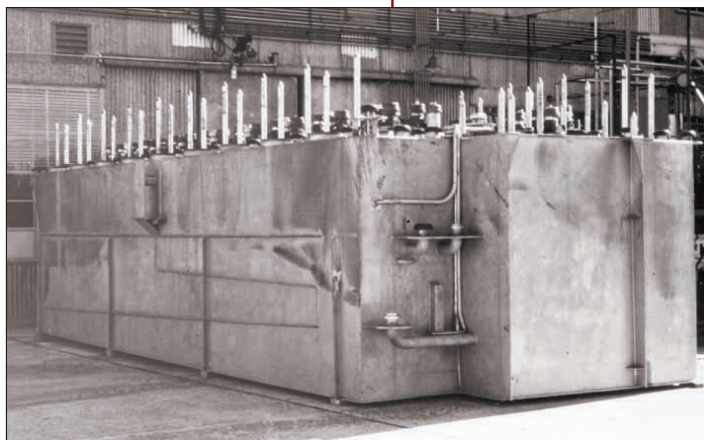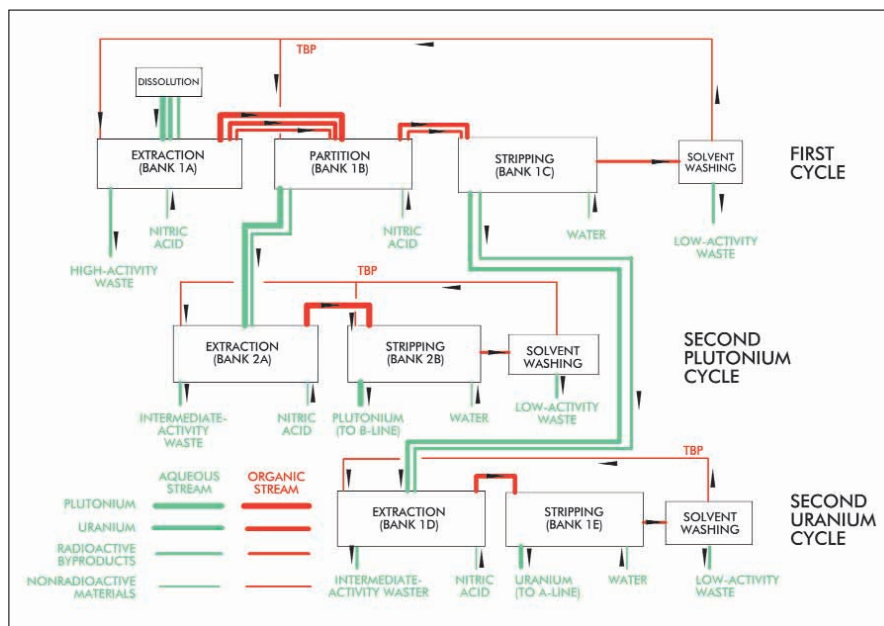

Development of the Purex process for plant-scale operations was undertaken at both Oak Ridge and Knolls Atomic Power Laboratory, and pilot facilities were operated at Oak Ridge. Although Oak Ridge was the focus of separations development at the time,[7] the Atomic Energy Commission had asked Knolls laboratory to construct an experimental facility called the Separation Process Research Unit (SPRU) to support Hanford separations process development, and this facility was used for Purex development as well. A tentative flow sheet for Purex had been worked out by October 1950, and by a year later much of the initial data needed to establish operational parameters had been provided by Knolls and Oak Ridge. To supplement data from those facilities, a semiworks facility called TNX (Building 678-G) was constructed at Savannah River. At TNX, experiments using mockups of the specific equipment to be installed at Savannah River were conducted.[8]

THE PROCESS STEPS

The initial process for plutonium and uranium separation at Savannah River involved five major steps: dissolution, head–end treatment, first–cycle, second–cycle uranium, and second–cycle plutonium. The last three steps comprised the Purex process *per se*. Most Purex plants have included head–end treatment, and dissolution is a necessary first step.[9]

Dissolution The first step in processing materials irradiated in the reactors was the conversion of the solid reactor assemblies to a liquid. Assemblies were placed in a dissolver, to which caustic solutions were added to remove the aluminum cladding. The resulting solution was transferred to the waste tanks. Nitric acid was then added to the dissolver and heated to aid dissolution of the assemblies.[10]

Head-End Treatment Not at first considered necessary, by the spring of 1951 process development research showed head-end treatment to be essential to effective Purex processing. The head-end treatment involved centrifuging the solution to remove zirconium and niobium fission products as well as solids from the solution sent from the dissolver.[11]


Purex incorporates three main steps: first cycle, where plutonium is separated from uranium; second–cycle plutonium, where the plutonium is purified; and second–cycle uranium, where the uranium is purified. Sources: W. P. Bebbington, The Reprocessing of Nuclear Fuels, *Scientific American* 235, no. 6 (December 1976): 32–33; J. L. Swanson, Purex Process Flowsheets, in *Applications of Tributyl Phosphate in Nuclear Fuel Reprocessing*, ed. Wallace W. Schulz, Leland L. Burger, and James D. Navratil, Science and Technology of Tributyl Phosphate, vol. 3, (Boca Raton, Florida: CRC Press, Inc., 1984), 57–59; and C. S. Schlea and A. S. Jennings, Behaviour of Actinides and Fission Products in Tri-n-butyl Phosphate and in Di-2-amyl 2-butylphosphonate Solvent Extraction Processes Using Short-residence Contactors, in *Solvent Extraction Chemistry of Metals*, ed. H. A. C. McKay, T. V. Healy, I. L. Jenkins, and A. Naylor (Toronto: Macmillan Publishing Company, Inc., 1965), 83–84.

First Cycle The Purex process began with the first cycle. In this step, uranium and plutonium were extracted from the liquid containing the fission products, then partitioned from each other for further processing. The first cycle took place in the hot canyon. The main equipment pieces were three mixer–settler banks developed by Knolls Atomic Power Laboratory and TNX.[12]

Prior to being sent to the first mixer–settler unit (Bank 1A), the solution containing plutonium and uranium was chemically adjusted to meet specifications for extraction.[13] In Bank 1A, a 16-stage mixer–settler unit, the aqueous and organic phases were brought into contact with each other to form extractable complexes with the TBP in the organic phase, then the two phases were allowed to separate, extracting the plutonium and uranium from the fission products, which stayed in the aqueous phase. The second step was performed in Bank 1B, where an adjustment of the solution chemistry and further mixing and settling caused the plutonium to be stripped from the organic phase to the aqueous but left the uranium in the aqueous, a step called "partitioning." And finally, in Bank 1C, the uranium was similarly stripped from the organic phase.[14]

Second–Cycle Plutonium The original second–cycle plutonium step used two 16-stage mixer-settlers, Banks 2A and 2B, to further purify the plutonium from the first cycle. The plutonium from the first cycle was oxidized to the tetravalent state for feed to the cycle. In Bank 2A, the plutonium was mixed into countercurrent aqueous and organic streams, where it would form complexes with the TBP and follow the organic stream, while most of the residual fission contaminants would stay with the aqueous stream. In Bank 2B, the plutonium was reduced to the trivalent state and again moved back to the aqueous phase. The aqueous stream carrying the plutonium was then sent to a holding tank, from which it was delivered to the B-Lines to be converted into metal.[15]
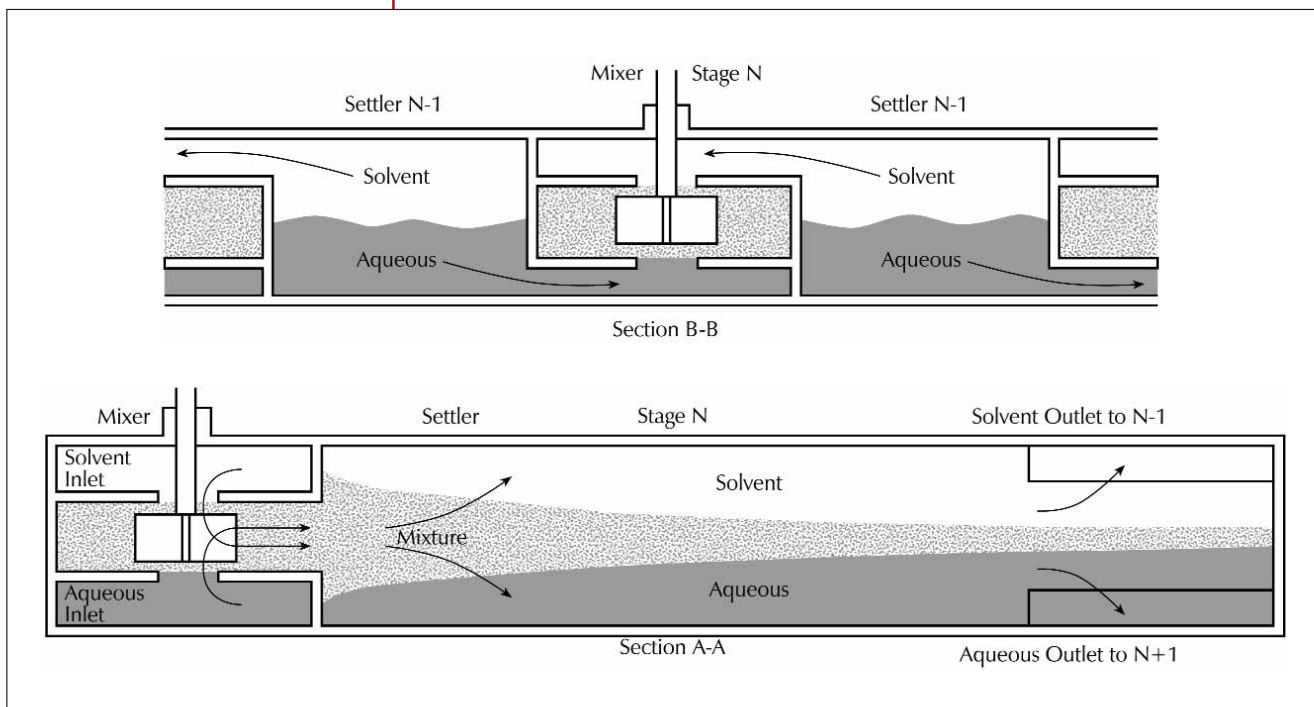
Line drawing of mixer-settlers. Mixer–settlers combine the aqueous and organic solutions in mixing chambers, then allow the two to separate into individual phases in settling chambers. Each pair of mixing and settling chambers is called a stage. The original mixer–settler units at Savannah River each contained 12 or 16 stages. Source: W. P. Bebbington, The Reprocessing of Nuclear Fuels, *Scientific American* 235, No. 6 (December 1976), 35.

Second–Cycle Uranium The second–cycle uranium step, which took place in Banks 1D and 1E, served a similar purpose as second–cycle plutonium, namely greater removal of fission byproducts and further extraction of any plutonium carried with the uranium through Bank 1B. The uranyl nitrate solution from Bank 1C was concentrated and adjusted as desired and fed to Bank 1D to undergo another series of mixing and settling.[16]

LIQUID TO METAL—THE B-LINE

Plutonium was converted from a liquid to a solid metallic form in a shape called a button in the canyon's B-Lines. The buttons were sent to other sites in the national weapons complex to be forged into final weapons components. The B-Lines were also known as the button lines, and some early descriptions used the term "isolation area."[17]

Du Pont personnel drew largely from experience at Los Alamos and Hanford in developing the button line process, and early descriptions of the Savannah River process closely resemble that used at Los Alamos.[18] But operations at these sites were basically at the pilot-plant scale; the Savannah River process needed to be a plant-scale, integrated means of converting plutonium to metal. Coupling, the procedure for concentrating the plutonium solution received from Purex operations and preparing it for conversion to metal, required a considerable development effort. Research for this step took place mainly at Knolls Atomic Power Laboratory and Oak Ridge.

Evaporation was the first choice for a means of concentrating the solution. But an explosion in an experimental evaporator at TNX caused the Du Pont engineers to abandon

Explosion and Change—Ion Coupling

Concentrating plutonium from the second cycle to prepare it for B-Line processing initially involved evaporating the excess nitric acid. The Blaw-Knox Construction Company designed an evaporator for experimental work in 1951, which was tested at Oak Ridge; research using a different design of evaporator was conducted at Knolls. By the end of March 1951, however, Du Pont's L. C. Peery (who was directing Du Pont work at Oak Ridge) had suggested that personnel at Oak Ridge might have a better method than evaporation—an ion–exchange process.

By mid-September, enough work had been done on the ion exchange process that it served as a definite rival to evaporation. On December 5, 1951, ion–exchange coupling was noted to have been "added to B-Line," although this may only have meant that consideration was given to installing either process or that the process would be installed later in the H Area. Oak Ridge personnel were to work on refining the process during 1952 and 1953, and evaporator research continued at TNX.

On January 12, 1953, during the 4 to 12 shift, the TNX evaporator exploded. Investigation into the cause of the explosion found that distillate from the evaporator contained TBP and a kerosene-like diluent, which meant that part of the organic phase had been transferred to the evaporator with the aqueous phase from the experimental second cycle stream. Reaction of the TBP with other materials in the solution was determined to be the most likely cause of the explosion, and there was a chance that the same could happen in the canyons during plant operation.

By March 1953, sufficient data had been compiled to determine that the evaporation process was unsuitable for installation in the B-Lines, and the "[t]riple evaporation coupling process [was] eliminated

from Building #221 B-Line." The coupling step would be provided by the ion-exchange process developed at Oak Ridge. Until this time, B-Line construction and equipment acquisition efforts appear to have proceeded under the assumption that evaporators would be installed. Manufacture of the evaporators was far enough along that the order could not be cancelled after the explosion, so the evaporators were received and placed in storage.


TNX explosion. Courtesy of SRS Archives, negative M-236.

Sources: *Savannah River Plant Engineering and Design History, vol. 1, Text and Exhibits*, Document Number B-989-3-5 (Pittsburgh: Blaw-Knox Company, June 30, 1954), 140, 143, and 150; R. M. Girdler, "Chicago Meeting—September 18–19, 1951, Separations Development Program," memorandum, October 3, 1951, Acc. 1957, Series IV, Box 45, Folder 7, 2, Hagley; F. S. Chambers to L. C. Peery, "Plutonium Isolation," April 5, 1951, Acc. 1957, Series IV, Box 44, Folder 5, 1, Hagley ; Girdler, "Chicago Meeting—September 18–19, 1951, Separations Development Program," 2. F. S. Chambers to Lombard Squires, "Separations Development Programs for Fiscal Year 1953," memorandum, March 24, 1952, Acc. 1957, Series IV, Box 46, Folder 1, 4, Hagley.; T. J. Colven, Jr., G. M. Nichols, and T. H. Siddall, *Interim Technical Report, TNX Evaporator Incident January 12, 1953*, Document Number DP-25 (Aiken, South Carolina: Savannah River Laboratory, May 15, 1953), 8, NTIS; *Savannah River Plant History, All Areas, August 1950 through June 1953* (Aiken, South Carolina: Savannah River Plant, ca. 1954), 5–25; and *Savannah River Plant Engineering and Design History*, vol. 3, *#200-F&H Areas*, Document Number DPE-972 (Wilmington, Delaware: E. I. du Pont de Nemours and Company, Inc., January 1957), 77.

that process for a safer means of concentration under investigation at Oak Ridge, where cation exchange columns were being used. These were long tubes packed with a resin in the form of small beads that had exchangeable hydrogen ions. In dilute nitric acid, the resin beads would hold onto the positively charged plutonium, while in strong nitric acid they would release it. The plutonium from the Purex process was pumped to the fourth level of the canyon building; the valence was adjusted to provide plutonium ions that would be strongly attracted by the resin, then the solution was passed through the columns. Next, sulfuric acid was passed through the columns to remove uranium absorbed with the plutonium, then sulfamic and nitric acids were used to desorb the plutonium from the resin, giving a concentrated solution.[19]

The next B-Line steps were precipitation and filtration. In the precipitators, hydrogen peroxide was added, which reacted with the plutonium to form crystals of plutonium peroxide. After settling to the bottom of the precipitator as a sludge, the plutonium peroxide was filtered in a "filter boat" to produce a cake of plutonium peroxide. Still in the filter boat, this cake was transferred to a conveyor, the beginning of the "mechanical line."

In the mechanical line, the plutonium cake was dried by drawing air through the filter boat. The boat was then moved by conveyor to a furnace where it was heated as first air, then hydrogen fluoride and oxygen were passed through it to produce plutonium tetrafluoride. Calcium, and originally iodine, were added to the plutonium tetrafluoride at a mixing station, then the mixture was emptied into a "bomb," or pressure chamber, that contained a magnesium crucible.[20] The bomb was placed in a reduction furnace, the atmosphere in the bomb was replaced with helium, then the materials were heated to form metallic plutonium. The crucible was broken to free the button, which was cleaned, then packaged and sent to the storage vault.

Most B-Line operations were carried out in gloveboxes and cabinets. The cabinets, some nearly 50 feet in length, housed the various equipment and conveyors that transferred material from station to station. Operations that were not carried out mechanically were conducted by operators working through glove ports.[21]

The A-Line process consisted of four steps (three when the silica gel column was not needed for removal of fission products) and involved first, the concentration of uranium-containing liquid, then the conversion of the liquid to uranium oxide. Source: W. C. Perkins, W. S. Durant, and M. L. Hyder, *The Safety of UO^3 Production in the A-Line at the Savannah River Plant*, Document Number DP-1449 (Aiken, South Carolina: Savannah River Laboratory, (March 1977), 11 and 14-15.
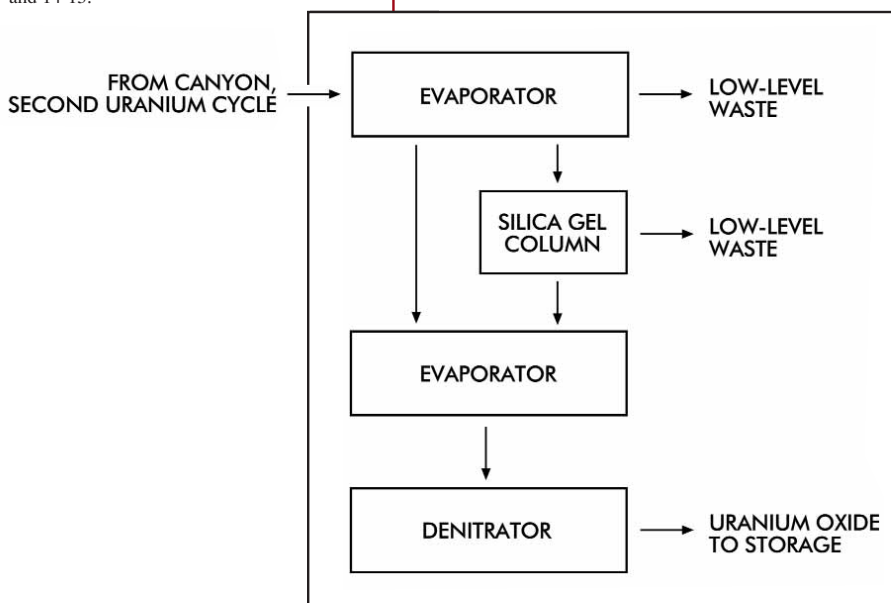
RECYCLING URANIUM—A-LINE

The purpose of the A-Line was to process uranium-containing solution generated by the solvent extraction process for storage and reuse, either at Savannah River or at other facilities. The A-Line received uranyl nitrate solution from the second uranium cycle, then concentrated the solution and converted it into uranium oxide powder, a stable form for storage or shipment.

The solution containing uranium was sent from the canyon second-cycle uranium banks to a storage tank. From there it was fed to a continuous evaporator, which boiled off liquid (mainly water and nitric acid). If necessary, this concentrated solution was then passed through a silica-gel column to remove radioactive contaminants. The second stage of evaporation continued the process of concentrating the solution; these evaporators were more specifically called hydrate evaporators. The final stage of denitration was carried out in pot-type denitrators that could process about a ton of uranium oxide each. In the denitrators, the solution became noticeably more viscous as it was heated, eventually acquiring the consistency of dough. At this stage, the mixture had to be continuously agitated so it would not harden into one large mass. With continued agitation and removal of moisture, the dough became a powder. After cooling it was vacuumed out and then pulverized and blended, and finally packed into steel drums lined with resin for storage or shipment elsewhere.[22]

TRITIUM

The extraction and purification of tritium was an entirely different process from that used for extracting and purifying plutonium. Not only did the process involve working with gas instead of liquid, it involved working with an isotope of hydrogen, the smallest and most difficult chemical element to contain.

The tritium purification process for Savannah River can trace its origins to development work by General Electric for tritium extraction facilities at Hanford (one installed, and a second under development by November 1950), and to early experience in tritium separations at Los Alamos. The Hanford equipment setups were known as M-Lines. M-Line tritium was sent to Los Alamos for further purification in their thermal diffusion column. The tritium facility eventually installed at Savannah River combined both these steps.[23]

Development work on the process was an on-again, off-again affair due to uncertainties about the nation's need for tritium.[24] At one point, the line being manufactured for Hanford was to be installed at Savannah River, but an improved and better-integrated process was developed instead. General Electric built a prototype that was installed at Knolls to provide process and operations data for the full-scale line. By the end of 1951, the Atomic Energy Commission requested that only a minimal tritium separations facility be built at Savannah River, designed to make later expansion easy.[25]

Although the Atomic Energy Commission again changed its plan for the Savannah River tritium facility in early 1953, this change did not affect the initial tritium process developed for the F Area. The 1953 decision called for a new, larger, and much improved tritium extraction facility to be built in H Area. The minimal facility was constructed in F Area (Building 232) according to General Electric designs. The process lines built by Consolidated Vacuum Corporation; installation began in early 1954.[26]

THE PROCESS STEPS

The F-Area tritium extraction process included five main steps: extraction (including receipt of the assemblies, drying, and decanning), primary separation, stripping, isotope

separation, and packaging. All but the initial processing steps took place in stainless steel hoods.

Irradiated lithium–aluminum assemblies were shipped from the reactors to F Area by truck in shielded casks. A monorail hoist was used to move the cask into an air lock and onto a transfer car driven by a detachable car called a "mule." The mule and transfer car, after being monitored for gamma radiation, moved along tracks to a storage area, where the transfer car was secured with latches and the mule taken away. The assemblies were removed from the casks by remote lifting mechanisms and master–slave manipulators, then dried in heated air, as were the crucibles into which the slugs would be placed. This removed moisture, and, in the case of the crucibles, also released gases absorbed during prior extraction cycles. Finally, the outer aluminum coverings that encased the elements were cut lengthwise by a decanning machine, and the slugs were added to the crucible. The crucible containing the irradiated elements was then placed into a hood and evacuated, then heated to release the gases from the slugs.[27]

The irradiated assemblies were lifted from the cask cars by remote-lifting mechanisms. Courtesy of SRS Archives, negative DPSPF-41138-2.

The gases released by the slugs were removed from the crucibles by mercury diffusion pumps and Sprengel pumps, then drawn through palladium diffusers. Each original diffuser contained four palladium membranes that were maintained at varying temperatures. The palladium membranes would remove about 95% of the hydrogen (as tritium, deuterium, and protium) from the gas that passed through them.

The waste gases from the diffusers still contained approximately 5% hydrogen, which was removed by a process called stripping. The gases were passed through a bed of palladium powder and silica sand heated to 100º C, which absorbed almost all the remaining hydrogen. Gases thus stripped that had a tritium content of 0.1% or less were released to the atmosphere. After gas from two charges was passed through the stripper bed, the bed was heated slightly to release the hydrogen, which was returned to the palladium diffuser.

Tritium was separated from the other hydrogen isotopes by a process called thermal diffusion, which was accomplished by a simple 24-foot-long stainless steel column set vertically, with a water jacket surrounding its exterior and a heated molybdenum wire running lengthwise through its center. The mixture of hydrogen isotopes was fed at a controlled rate to the column near its center. The lighter protium and deuterium atoms would tend to concentrate in a rising stream near the hot wire, and the heavier tritium atoms would tend to move downward near the cool outer wall. The protium and deuterium were continuously drawn off at the top of the column, and tritium—of a purity of 99% or higher—was drawn at the bottom. The tritium was then placed in containers and sent to the vault building in F Area, where it remained until shipped off the site.[28]

AREA DESIGN AND CONSTRUCTION

The design of the separations facilities at Savannah River drew from a wide range of sources: from Du Pont's past experience in the chemical industry, from World War II and post-World War II experiences at Hanford, and from the knowledge and understanding then being accumulated at the fledgling national laboratories system. The canyons built at Hanford during World War II, for using the bismuth phosphate process to extract plutonium, served as a design basis for the Savannah River canyons. The engineers and architects contributing to the designs came from Du Pont; the Blaw-Knox Construction Company, which was the initial general subcontractor for architect–engineer services in this area; American Machine and Foundry Company and Gibbs and Hill, both responsible for special equipment design work; the Schutte-Koerting Company; the Penberthy Injector Company; and the Allstates Engineering Company. Initial plans for Savannah River called for only one separations area, but by the end of 1950 Du Pont had specific instructions to plan on two separations plants (F and H Areas) and consider a possible third plant, identified as X Area.[29]

As first conceived, F and H Areas had similar plutonium separation facilities, but the plutonium shapes would be manufactured in F Area only, and all A-Line operations would be located there as well. The F Area contained four primary process-related buildings: the

H AREA

Basic Information Map, 1956. The original layout for the H Area. The most important facilities are the canyon building, the new tritium Manufacturing Building, fan house, canyon stack, and the sand filters. Source: Basic Information Maps, 200-H Area, 1956.
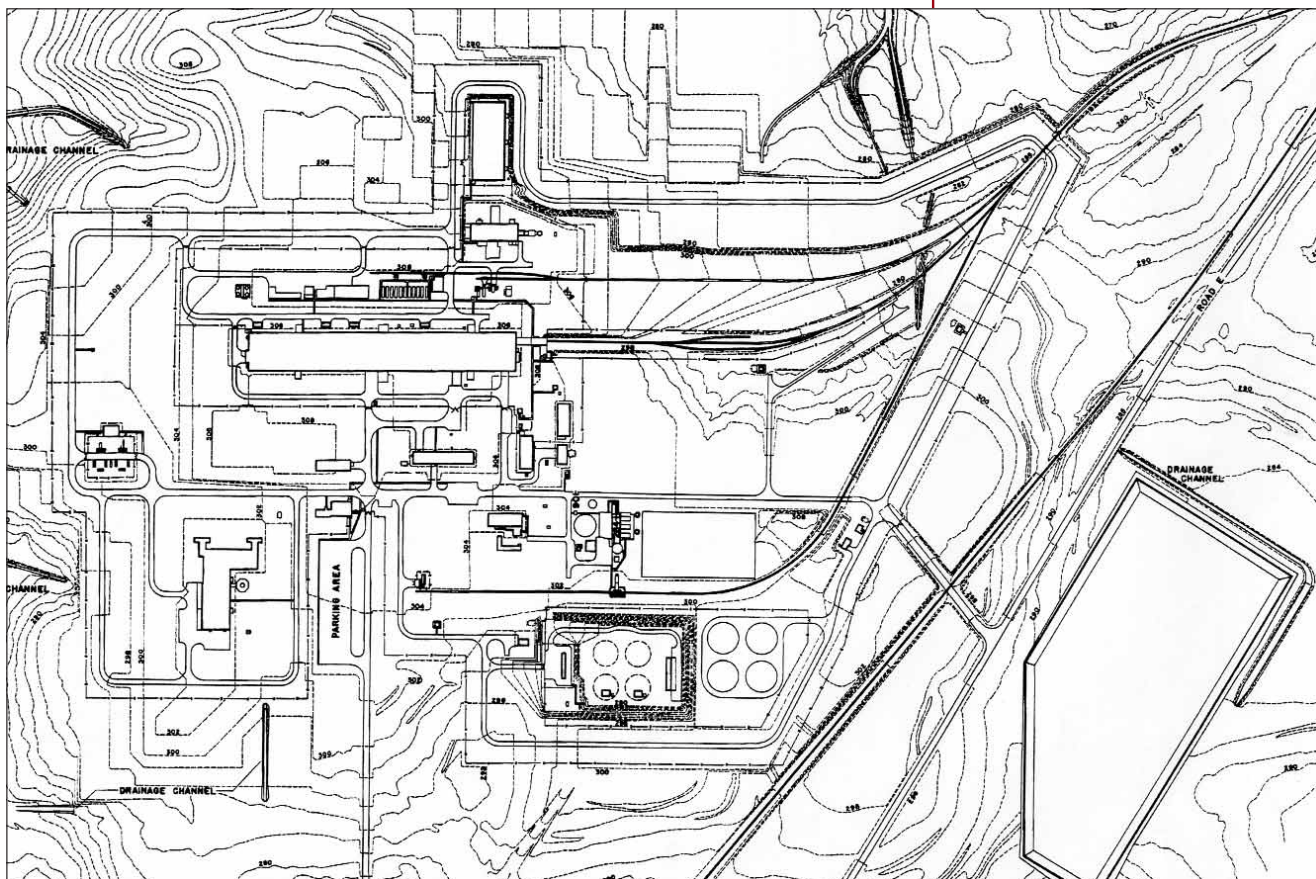
canyon, which housed Purex and B-Line operations; the A-Line associated with the canyon; the Manufacturing Building, where tritium was extracted, purified, and packaged; and the Metallurgical Building, where the plutonium was to be fabricated into weapons components—something that never occurred. H Area was to contain only the basic production buildings, but included space for more complete facilities if future production demands warranted their construction. Both areas were to have their own support facilities for the generation of process steam, water and air supply, and filtration, and for materials storage—but only one area analytical laboratory was to be built, located in F Area.[30]

The design of the facilities incorporated some standard chemical industrial features such as central control panels and remote operation capabilities. Special design considerations included: shielding, segregation of the process steps by the radioactivity of the materials being processed, ventilation, the manner of servicing the equipment, the nature of the waste and means of treating it, the number and placement of sampling stations, the degree of automation, the type and organization of equipment (including using gravity flow as opposed to pumping solutions), the control of fissile materials to avoid criticalities, and contamination control (from washing contaminated clothing to preventing radioactive solutions from backing up into process piping intended for inactive solutions).[31]

> The dangers of working with radioactive elements and Du Pont's safety culture made it imperative that worker safety be a major factor driving design. "It was basic that every possible precaution should be taken to guard personnel against exposure to radiation beyond established tolerances. In the #100 and #200 Areas, this was accomplished through the use of both concrete and metal shielding around critical areas, by the use of remote handling equipment to manipulate the in-process materials, and by radiation monitoring and alarm systems."[32]

Another aspect of area design was the relation between the canyons and the waste tank areas. The canyons were designed to use gravity to discharge wastes, so the canyons had to be set on the highest ground in the area. Initially, a single waste-storage area was to serve both F and H areas, but providing the proper slope for transfer piping was problematic, so separate waste facilities were provided for each. Once the locations of the canyons and waste areas were established, the other buildings and facilities could be placed "from the standpoint of economy and their relationship to the over-all process."[33] Buildings that supported canyon operations—such as the chemical feed tanks, the canyon stacks, the fan houses, the sand filters, and the F Area A-Line and laboratory—were placed adjacent to the canyons. The tritium-extraction facilities and the Metallurgical Building were less closely associated with canyon operations and so could be placed where suitable ground was located. The Product Storage Vault was placed in an inconspicuous corner of the F Area to give as little indication of the importance of its contents as possible.[34]

As originally designed, the F and H areas had about 50 buildings each, for which over 300 acres of land were graded and more than a quarter of a million yards of concrete were poured. Construction work began in June 1951 with the initial grading and setup of temporary facilities in F Area. The same activities began in H Area in September.

Among the factors that extended the major construction peri-od [for F Area] were the low priority of completion of the 200-F Area with respect to force, materials and equipment. This was particularly true of pipefitters, electricians, and the mechanical crafts. Since the 200 Areas performed the last operating phase in the manufacturing process, overall scheduling placed the 200 Areas as the last to go into operation, and the 400, 300/700, and two of the 100 Areas were given priority over them.[35]

The majority of the F Area construction had been completed by the end of December 1954, and most of H Area was completed by the following spring.[36]
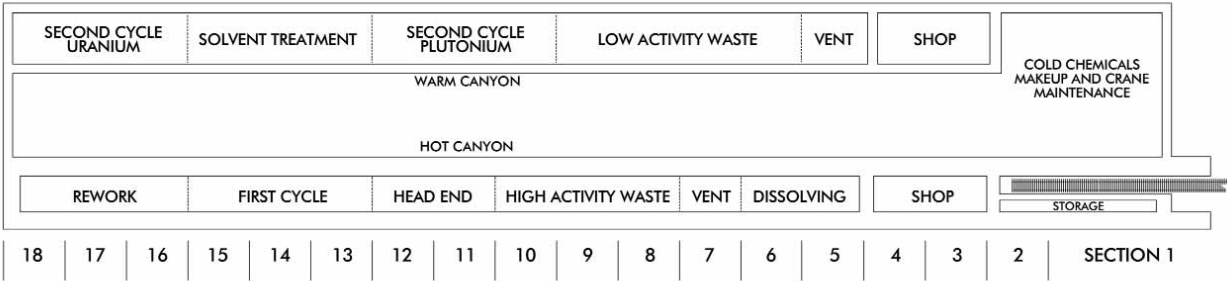
CANYONS AND B-LINES

Many canyon features were based on Hanford Building 221-T, the Cell Building.[37] The Savannah River canyons were approximately four stories tall, situated partially below grade, and enclosed two open processing areas that ran almost the length of the buildings. These areas were called canyons and gave the informal name to the buildings.[38] At Hanford, the most radioactive solutions were dealt with in the Cell Building, and work with the less radioactive solutions were conducted in the Bulk Reduction Building. These two Hanford buildings became the hot and warm canyons in the Savannah River canyons. And the interior division into cells at Hanford's canyons was eliminated in South Carolina in favor of continuous open process areas. At Savannah River, the hot and warm canyons were situated on either side of a central section that included control rooms, feed tanks, equipment, and piping for non-radioactive solutions. Processing flowed from south to north in the hot canyon, then to the appropriate warm canyon equipment and to either the A-Line or the B-Line.[39]
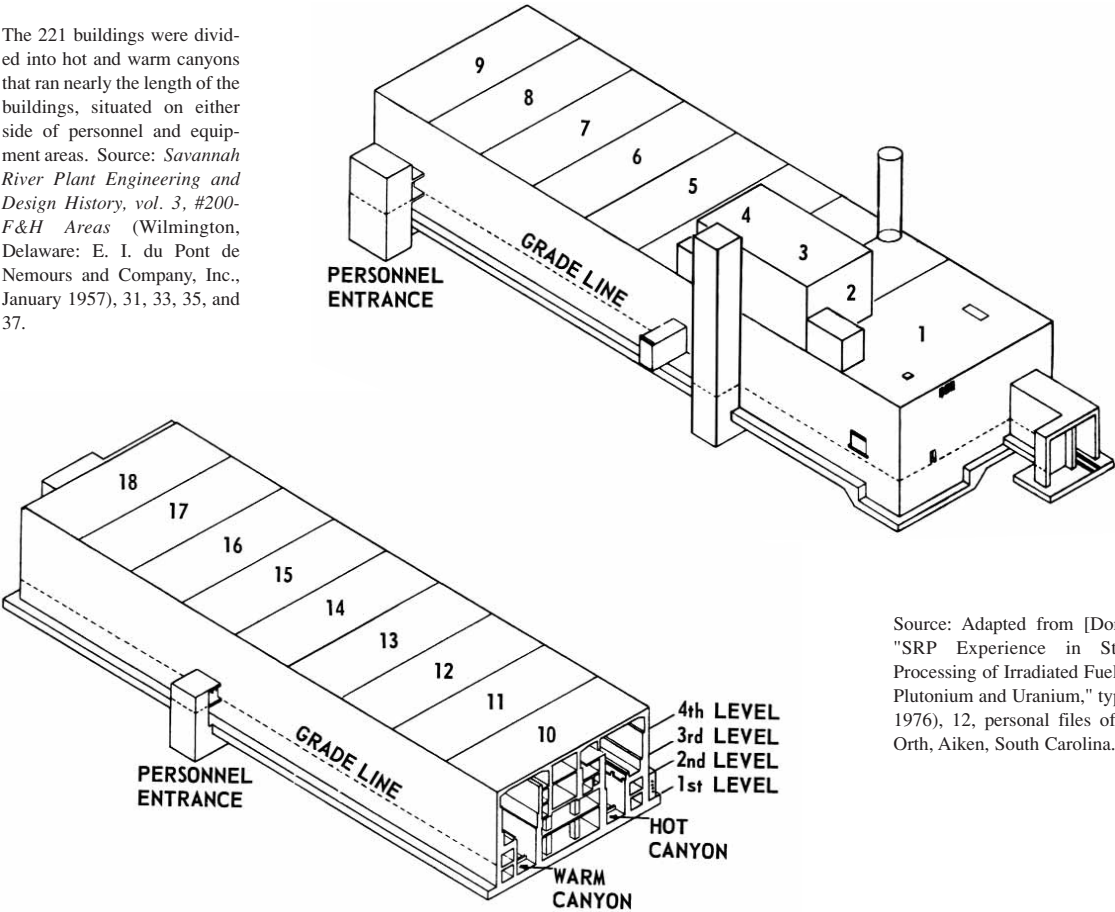
Cellular construction was discarded and one continuous canyon building was proposed. Further study of this design led to doubling back half of the single canyon [Hanford's Cell Building had one row of process cells] and placing the two halves side by side, with common facilities for each incorporated in one general area serving both. A number of layouts based on this plan, and some application of model work by Blaw-Knox, assisted in estab-lishing an efficient design.[40]

The most important design criterion for the buildings was to incorporate remote oper-ation, which offered a means of better limiting radiation exposure to operations personnel. This meant that all processes were controlled from behind thick concrete walls; irradiated reactor elements entered the separations process by a remotely operated crane, and equip-ment was exchanged via the same crane. The goal was to keep exposures at no more than 1/1000 rem per hour in operating areas, and at no more than 6/1000 rem per hour in areas less frequently occupied.[41]

Processing Areas in the Savannah River Canyons

SECOND CYCLE URANIUM	SOLVENT TREATMENT	SECOND CYCLE PLUTONIUM	LOW ACTIVITY WASTE	VENT	SHOP	COLD CHEMICALS MAKEUP AND CRANE MAINTENANCE

WARM CANYON

HOT CANYON

REWORK	FIRST CYCLE	HEAD END	HIGH ACTIVITY WASTE	VENT	DISSOLVING	SHOP	STORAGE

18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	SECTION 1

The 221 buildings were divided into hot and warm canyons that ran nearly the length of the buildings, situated on either side of personnel and equipment areas. Source: *Savannah River Plant Engineering and Design History, vol. 3, #200-F&H Areas* (Wilmington, Delaware: E. I. du Pont de Nemours and Company, Inc., January 1957), 31, 33, 35, and 37.

9
8
7
6
5
4
3
2
1

GRADE LINE

PERSONNEL ENTRANCE

18
17
16
15
14
13
12
11
10

GRADE LINE

PERSONNEL ENTRANCE

4th LEVEL
3rd LEVEL
2nd LEVEL
1st LEVEL

HOT CANYON

WARM CANYON

Source: Adapted from [Don A. Orth], "SRP Experience in Storing and Processing of Irradiated Fuel to Recover Plutonium and Uranium," typescript (ca. 1976), 12, personal files of Donald A. Orth, Aiken, South Carolina.

At the end of the design process, F canyon was a Class I building almost three football fields in length that housed two processing canyons. The building was divided into 18 sections, initially of equal size, extending across its width. Just prior to the freezing of the design, the length of Section 1 was increased to allow additional room for movement of materials and equipment into and out of the canyon; the other sections were equal in length. For the purpose of locating equipment, each section was divided into four square modules (basically equipment stations—these were not divided by walls). The north wall of the building was designed so that it could be easily removed if the building needed to be expanded.[42]

Initially, the designs for the two canyon buildings were nearly identical, but experience gained during the construction and early operation of the F-Area canyon provided the means for design improvements, cost reductions, and equipment installation and layout modifications in H Area.[43] Construction of the F-Area canyon began at the end of June 1951, and the canyon equipment was installed by the end of October 1953. The building was complete enough to turn over to operations in early April 1954.[44] The H-Area canyon construction began in late September 1951. During construction, continuing development work was undertaken to increase processing capabilities. By March 1955, when the building was turned over to operations, adjustments had been proposed or made to the head-end equipment, high-activity waste equipment and process, the solvent recovery system, and other equipment pieces and process steps, "all of which should improve continuity of operation."[45]

Standardization of design was essential to each canyon's future efficiency as a remotely-controlled facility and for future maintenance. Flexibility was equally important:

> Building #221-F basic design criteria called for remotely operated and maintained processing equipment to insure a proven, safe and efficient way to produce decontaminated plutonium solutions and decontaminated uranyl nitrate solutions. In order to meet this design requirement basic criteria of safety, reliability, simplicity, interchangeability, standardization, and flexibility were adopted. These principles of design were applied to both building and equipment and particularly to the canyon equipment, piping, and other facilities required for materials handling and remote maintenance. In fact, emphasis was placed on structural flexibility and the principle that the building should not be designed for any specific piece of equipment. An example of this is the flexibility afforded by the uniform wall sections and embedded piping in the canyons. This design facilitates the rearrangement or relocation of equipment or operations in the future.[46]

TRITIUM

Just as the development of the tritium process for Savannah River was an on-again, off-again affair, so was the design of the physical plant.[47] Blaw-Knox initially proposed a

Piping the Canyons

One of the more demanding portions of construction in the canyons was the precision to which the process piping had to be installed. Through these pipes, chemicals were supplied to and transferred between the processing equipment. The piping system needed to allow relatively easy equipment removal and replacement. To accomplish this, banks of piping were set in the canyon walls, and trunnions were provided to precisely locate equipment within the canyon modules. Jumpers then provided the means of connecting the equipment to the piping. The embedded pipes had to be located accurately so replacement jumpers could be made in the future without entering the canyons to take measurements. To locate the pipes, beams were set up along the canyon walls and jigs used to align the pipes to a tolerance of no more than one ten-thousandth of an inch. Once the concrete was poured, variances were recorded on as-built drawings for future reference. Variances from one module to another do not exceed one-sixteenth of an inch.

Sources: *Savannah River Plant Construction History, vol. 3, Construction 100–R P L K & C and 200-F & H Areas* (Wilmington, Delaware: E. I. du Pont de Nemours and Company, Inc., January 1957), 206; and LeVerne P. Fernandez, "Savannah River Site Canyons—Nimble Behemoths of the Atomic Age," in *50 Years of Excellence*, 134.

choice of L- and T-shaped two-story buildings of Class I construction as most suitable to the processes to be housed. In October 1951, the work was stopped due to a reduction in the production requirements of the Atomic Energy Commission, giving engineers at Knolls an opportunity to study the feasibility of the integrated process then planned for installation at Savannah River. Du Pont expected the work to be on hold for approximately six months, but near the end of the year the Atomic Energy Commission requested that the design work resume. In mid-December Blaw-Knox began working on the design again.[48] Although the specifications for the building had been modified, the process equipment being designed was not altered by this change. By early 1952, General Electric had turned over a proposed equipment setup to Du Pont, and this was the design used for the equipment installed in the F Area Manufacturing Building.[49]

Late in 1952, the Atomic Energy Commission increased its emphasis on tritium production, and by January 1953, the projected schedules were impacting the design of the tritium facility once again. Plans were made to extend the F Area Manufacturing Building to add additional capacity, and by the end of February, a new Manufacturing Building with two process lines was added to the project. In March, it was determined that the new building would be located in the H Area and that its capacity would be double that of the facility in F Area.[50]

Building 232-F, the first tritium facility at Savannah River, 1953. Much smaller than the tritium separations building in H Area, Building 232-F operated only a few years and can be viewed as a pilot plant for the vastly improved H Area tritium facility. Courtesy of SRS Archives, negative DPSPF 2-604.

Increased pressure to complete the F Area building delayed work on the new tritium facility. Extensive and time-consuming modifications were needed to improve the efficiency of the process, but time constraints limited the amount of improvements that could realistically be made, so the equipment setup was based on that which was planned for F Area. By the end of July, Allstates Engineering Company and Voorhees, Walker, Foley & Smith were nearing completion of the building design, and the specific H Area location for the facility had been determined.[51] The new L-shaped Manufacturing Building enclosed more than twice the floor space of its counterpart in F Area and incorporated Class I reinforcement for the process area. Although not noted in the history of the design of this building, it is likely that the early L-shaped building plans for F Area served as a design basis. Before the building was completed, the commission again reduced its tritium requirements; as a result, the H Area building was completed, but no equipment was installed.[52]

Construction of 232-F began in early January 1953, and the building was turned over to operations at the end of June the following year. Excavation for the larger tritium facility in H Area began in January 1954, and the following month it was given priority over all other construction in the area. Although the later change in production schedules decreased the urgency for the facility, construction still proceeded apace, and the building was turned over to operations in February 1955.[53]

A-LINE AND OTHER FACILITIES

The design basis for the equipment in the A-Line facility was the Mallinckrodt Chemical Works plant in St. Louis, Missouri. For the sake of economy of construction and operations, the line was not housed in the canyon but in a separate building that could be built with less shielding and would require fewer access restrictions.[54] In April 1952, design responsibility for the A-Line was transferred from Blaw-Knox to the Lummus Company, which adopted a three-story Blaw-Knox design and added a fourth-level penthouse and a basement.[55] The interior surfaces were also designed to minimize dust collection by limiting shelves, ledges, and other details where dust could settle.[56]

Among the more elegantly simple structures at Savannah River were the sand filters, items that have provided surprising performance over the years. These were important components in the canyon ventilation system, used to remove radioactive particulate matter from the air before it passed through the exhaust fans and out the stack. The design of the sand filters was derived from operational data and experience from smaller units at Hanford. With the assistance of C. E. Lapple of Ohio State University, who was hired as a consultant for the filter development, the specifications for the Hanford filters were modified to create units suitable to the needs at Savannah River.[57]

Acidity in the filter matrix eventually resulted in the erosion of the concrete support structure, which resulted in a loss of filter material and a short release of activity. The holes in the concrete grate were blocked and normal performance was restored. However, these failures prompted consideration of replacement filters. Two new filters were constructed with steel grates as supports, as opposed to the concrete grates on the original filters. The new filters were placed in operation in parallel with the original filters, which continue to give satisfactory service.[58] "The variability in naturally-occurring sands makes the design of a filter more complex than simply creating a pile of sand."[59]
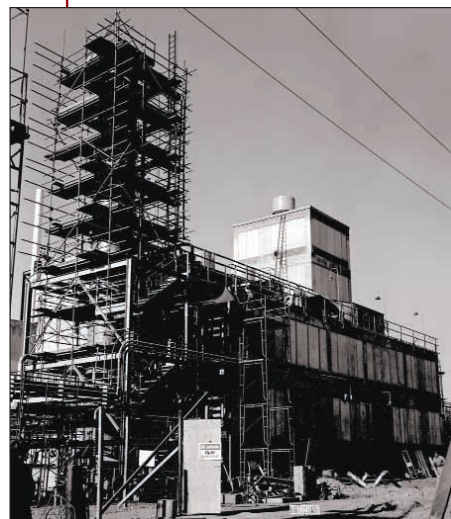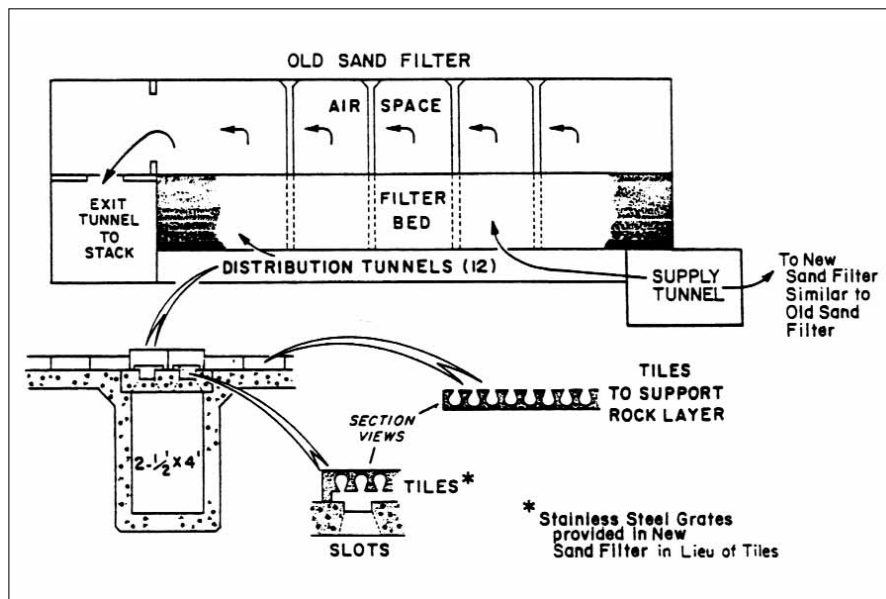
A-Line facility, November 1953. The H Area did not have an A-Line facility because the one in F Area was considered sufficient to handle all processing. Courtesy of SRS Archives, negative DPSPF 2-602-8.

Process air entered the sand filters through a tunnel from the canyon building, then passed out to the Fan House, and from there was vented to the stack. Once in the filter structure, the air was distributed underneath the filter bed by small distribution tunnels covered by slotted concrete covers, above which were set die-formed clay tiles. Above the tiles, were seven layers of graded gravel and sand that removed radioactive contaminants. A bypass tunnel allowed the air to be routed around the sand filter if needed. Source: *Waste Management Operations*, Document ERDA-1537 (Aiken, South Carolina: Savannah River Plant, September 1977), II-31.

A separations laboratory for analyzing products and operations in the 200 Areas was constructed in F Area. The laboratory was designated the Control Laboratory. As with the other laboratories around Savannah River, the Separations Control Laboratory assisted the other process-control laboratories and the main Savannah River Laboratory when needed.

The fundamental requirement for the design of the laboratory was versatility, since the methods of analyzing and assessing operations in the areas were not fully known at the time of design and would be subject to change during the operational lives of the separations facilities. The Control Laboratory was a one-story building with a basement, and was divided into four sections for metallurgical control related to operations in Building 235-F, Purex process control, A-Line process control, and other assistance to plant operations. Areas for handling plutonium analysis were segregated from the areas where low-level analysis was conducted by the arrangement of the change room and shower facilities. Work surfaces were designed to be easily decontaminated, and complex exposed surfaces where dust could collect were avoided—process piping, ductwork, and lighting were concealed behind hung ceilings. Construction of the laboratory began in October 1951, and the building was turned over to operations in early 1954.[60]

The Mockup Building in the F Area served as the main shop for the fabrication and test assembly of equipment, and for the routine maintenance and inspection work for the separations areas. The original Mockup Building included two bays running the length of the building. In the high bay were machine and metalworking equipment and the test assembly facilities. Other shop facilities, offices, and personnel areas were located in the low bay. The design was based on a similar building at Hanford.[61]

The mockup of all pieces of equipment that would be remotely operated and maintained in the 200 Areas was accomplished in Building 717-F. The personnel responsible for the mockup operations "received component parts of equipment… [which they] cleaned, inspected, identified and assembled into precise units. These units were then prefitted to other related units until a complete operating assembly was created. An 'As Built' record was made to record all pertinent dimensions of the assembly for reference in future fabrication. After this work had been done, the functional parts were placed in moisture-proof, weather-sealed bags in preparation for storage until they were required in the areas."[62]

The primary design consideration was that the mockup facility exactly duplicate the process equipment areas of the hot and warm canyons. Replacement jumpers and equip-

772-F Laboratory. Willie Simmons, Karen Felder, and Jim Johnson, Technical Assistants, in front of shielded analytical cells in 772-F Laboratory, 1978. Simmons and Johnson are remotely performing analysis and tests on radioactive samples. They are protected from the radiation by high-density concrete and a specially designed window that provides additional shielding. Courtesy of SRS Archives, negative DPSPF 27375.

ment, manufactured after operations began, would not fit if the canyon equipment stations were not precisely duplicated. The Mockup Building was used during construction for the mockup of equipment for the reactor areas as well.[63]
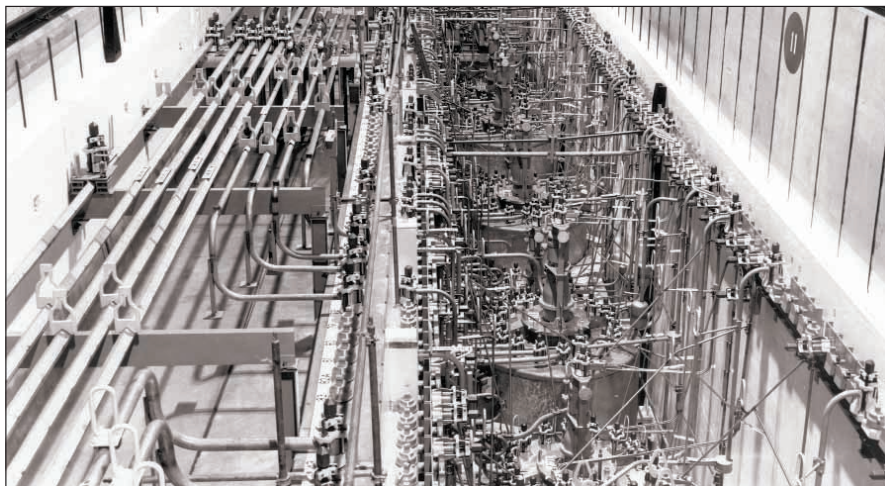
The mock-up facilities in the high bay are patterned exactly after the layout in the canyons of the #221 Buildings, including the slope of the floor, pipe nozzle locations and the equipment positioning guides. This made it possible, while the #221 Buildings were under construction, and in a clean location convenient to tools and material, to fit and assemble all canyon equipment and pipe jumper assemblies and to take measurements with the assurance that all equipment could be installed or replaced in the #221 Buildings by remote operations. After start-up, all new installations and replacements of process equipment will be 'mocked up' in this building.[64]
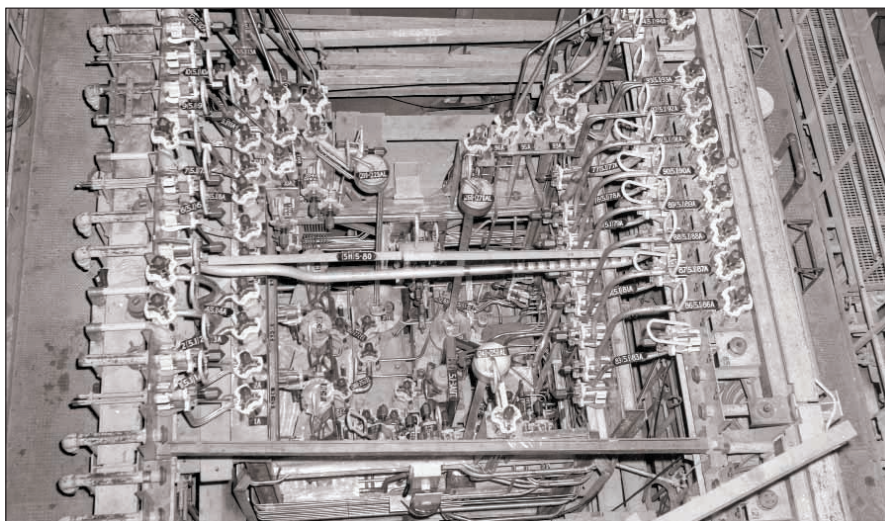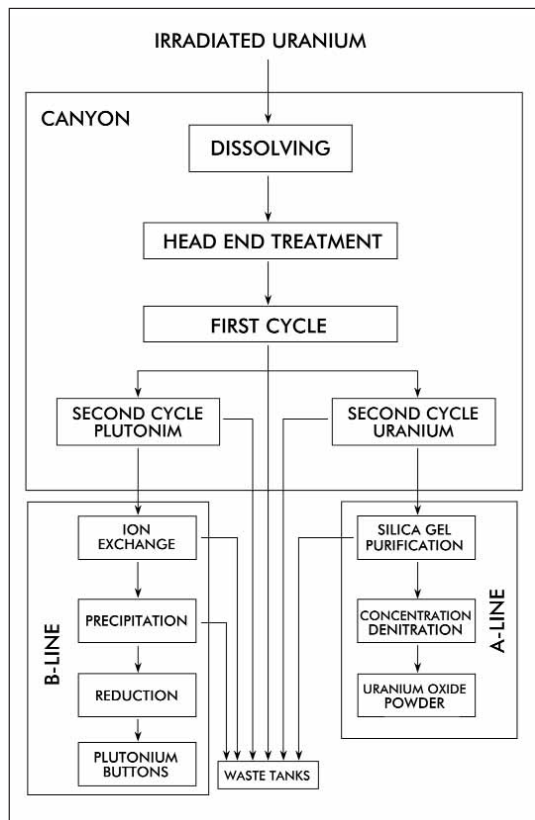

Interior views of canyon and comparison with canyon frame in Mockup Building. Courtesy of SRS Archives, negatives DPSPF 11568 and 7224-15.

One final building of interest was the patrol headquarters. During normal operations, the building served as the control point for personnel and vehicular movement into and out of the F Area. But in the event the main patrol headquarters for Savannah River became inoperable, F Area's patrol headquarters would become the emergency control center for the entire Savannah River plant. Disaster control facilities were located in the building, as were Army Teletype transmission and other communications equipment. The emergency control portion of the building was constructed according to Class I standards and was protected against gamma radiation by shielding in the walls and roof.[65]

(Opposite Page) 1. H Area power-house employees, 1957. George Stewart, Doug Hortin, Bob Felton, Joe Hall, (rear) Charlie Rice and Luke Cain, negative 4002-4. 2. Ray McJunkin plotting a standard calibration curve using atomic absorption spectrometer, negative DPSPF 27375-10. 3. Swimming Pool Area, Harold Harmon operating agitator for decontamination, 1975, negative 27226-75. 4. Shielded locomotive for moving cask into canyon, K. R. Taylor climbs aboard, 1978, negative 27226-78. 5. 221-F Control Room, left to right, O. L. Dobson, Jr., T. E. Philbeck, V. L. Rhoden, E. E. Haynes, H. E. Wright, and J. S. Bullington, 1963, negative 27226-63. 6. Hot Gang Valve Corridor, 1979. Left to right, L. E. Gattman, K. R. Taylor, and M. Davis, Jr. Negative 27226-79.

Originally, operations in both F and H areas followed this general scheme. All A-Line operations took place in the F Area. Source: Adapted from *Savannah River Plant Engineering and Design History, Vol. III, #200-F&H Areas* (Wilmington, Delaware: E. I. du Pont de Nemours and Company, Inc., January 1957), 23.
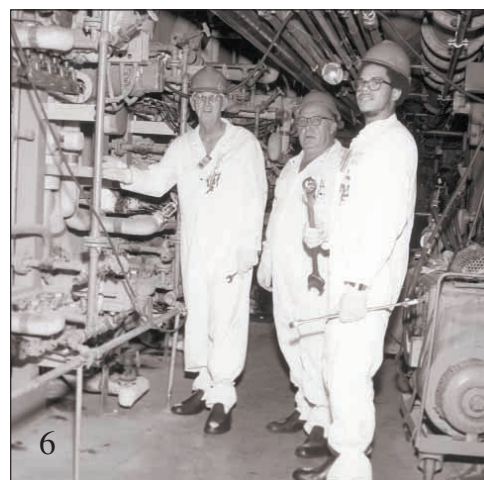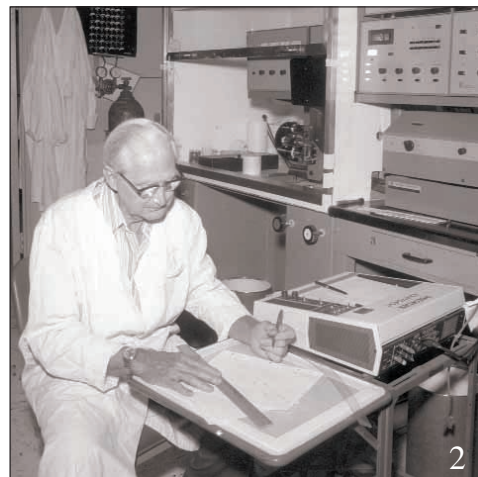
OPERATIONS

Liquid Separations

Operation of facilities in the separations areas, to approximately 1965, can be characterized as having been guided by two overarching and related efforts—to increase throughput, and to refine procedures. Improvements to the H Area canyon, based on experiences gained in F Area, enabled Savannah River to continue to meet production requirements while the F Area canyon was shut down from 1957 to 1959 for the installation of larger equipment and other modifications. The larger equipment, however, caused problems that had not been anticipated; adjustments to the equipment and the processes were made during the ensuing years, to work out a method of operation for plutonium separation, that remained virtually the same throughout the remainder of the operations history of the F Area canyon. Changes in tritium production requirements during the mid- to late 1950s made it necessary for the reactors to be loaded with enriched uranium. Special equipment and procedures were needed to separate enriched uranium, and this mission was undertaken in the H Area.[66]

The first irradiated material entered the F Area canyon in November 1954, and the canyon was able to operate at its designed capacity of about three tons of uranium per day. Throughput was increased slightly during the early months of 1955 as operators gained experience with the process and made small adjustments in the canyons and the B-Line facilities. The increased throughput made modifications to the A-Line necessary; a single-story addition and basement were built onto the south end.[67]

What Holds Separations Together

The H Area canyon went into operation in July 1955. Due to the improvements based on F Area's experience, the designed process rate of uranium per day accomplished in F Area was more than doubled in H Area operations. The need for even greater throughput, based on predictions for increased reactor operations, was imminent, and the combined button production capacity (two lines in F Area and one in H Area) was expected to be exceeded within two years.[68]

The conversion projects, explained in more detail below, were the focus of activities during the 1957 to 1960 period. As these projects were completed, participation in the Atomic Energy Commission peaceful uses programs expanded. Problems to 1965 included the contamination of the cranes in both areas (a recurring problem); corrosion in the canyon stacks, that resulted in releases of radioactive materials; a solution leak, that resulted in the plutonium contamination of a ventilation tunnel in the F Area canyon; malfunctioning gang valves in the canyons, that resulted in contamination of the routinely occupied gang valve corridors; the release of radioiodine from the canyon stacks; and a fire in the F Area primary recovery column. New technologies were also brought into the canyons during this period. In 1962, tests were begun on a closed-circuit television system for the canyons. And in the summer of 1965, the applicability of computers to separations process control began being studied.[69]
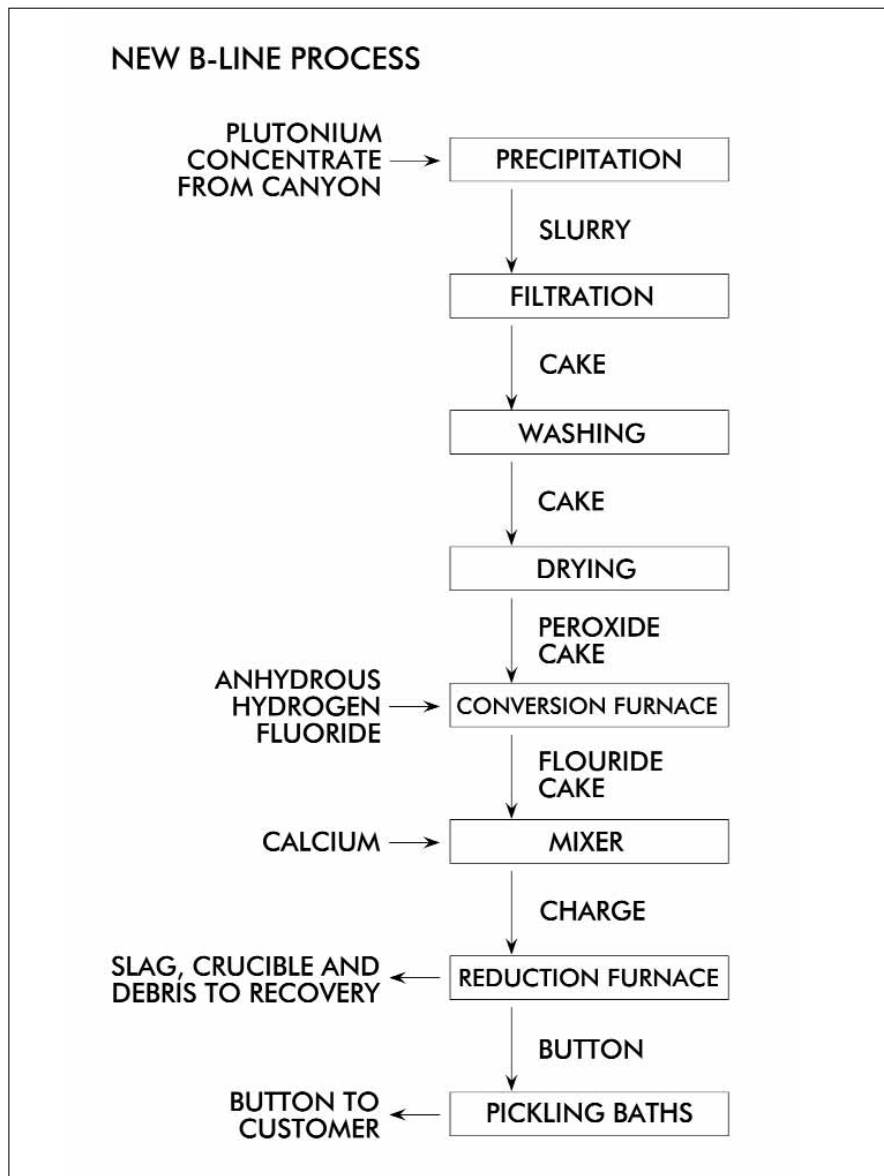
F Area Increased Throughput In 1957, the F Area canyon was shut down for a major renovation that would eventually increase throughput to nearly five times its initial capacity. Design work for the change began in early 1956, when new mixer–settlers, evaporators, and hold tanks were developed. As in the original design phase, pulse columns were considered in lieu of mixer–settlers, and means of securing columns were installed in the hot canyon, but mixer–settlers were again chosen because they could be more economically developed.[70]

The modifications included the B-Line facility as well. A trifluoride precipitation process, rather than the original peroxide process, was adopted because it was faster and more economical to operate. New criticality safe vessels were designed for handling large amounts of concentrated plutonium solution, and improved equipment designs were incorporated. To alleviate crowding, a new facility was constructed on the roof of the canyon.[71]

The increased throughput project involved removing most of the tanks and mixer-settlers and replacing them with the largest units that would fit in the canyon modules.[72] Some tanks were specially shaped to fit across two modules. The new, substantially larger mixer-settlers for F Area were called Jumbos. The units were developed at Savannah River's TNX facility and replaced the 1A, 1B, 1C, 1D, and 1E banks. The installation of the Jumbos and the other modifications related to the increased throughput project were completed in early 1959, and the F Area Purex facility went back into operation on March 19, 1959.[73]

Although there were great expectations for the Jumbos, they caused major problems and have been described as a mistake, that would have to be corrected for the next seven years. The problems began appearing almost immediately—plutonium began accumulating in Bank 1B, and excessive fission byproducts were following the plutonium through Bank 1A. By the summer of 1959, degradation of the solvent was expected to be at least part of the cause. Corrections involved extensive research and experimentation on the part of the laboratory, operations personnel, and Works Technical for several years. The solutions included ceasing the use of the decanters below the mixer–settlers, improving the

solvent recovery process, changing the solvent, and installing centrifugal contactors in the Bank 1A.[74]

NEW B-LINE PROCESS

```
PLUTONIUM
CONCENTRATE  ────▶   PRECIPITATION
FROM CANYON
                          │ SLURRY
                          ▼
                      FILTRATION
                          │ CAKE
                          ▼
                      WASHING
                          │ CAKE
                          ▼
                       DRYING
                          │ PEROXIDE
                          │ CAKE
                          ▼
ANHYDROUS
HYDROGEN    ────▶   CONVERSION FURNACE
FLUORIDE
                          │ FLOURIDE
                          │ CAKE
                          ▼
CALCIUM     ────▶       MIXER
                          │ CHARGE
                          ▼
SLAG, CRUCIBLE AND  ◀──  REDUCTION FURNACE
DEBRIS TO RECOVERY
                          │ BUTTON
                          ▼
BUTTON TO   ◀──        PICKLING BATHS
CUSTOMER
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The process used in the new B-Line in the F Area. Source: Adapted from E. W. Mainland, Donald A. Orth, E. L. Field, and J. H. Radke, Production of Plutonium Metal, *Industrial and Engineering Chemistry* 53, no. 9 (September 1961): 686–687.

While the canyon was shut down for the increased throughput project, significant changes to the B-Line were also undertaken. The rationalization for this modification was carefully developed by the personnel involved in getting it accomplished. The original B-Line was crowded and not well laid out. Safety issues were noted during a July 1958 safety review.[75] A plutonium trifluoride precipitation method was developed that offered a means of providing an integrated facility with new coupling, recovery, and metal production line.[76] The new coupling and precipitation systems featured slab-shaped tanks for increased nuclear safety in handling concentrated plutonium solutions. The metal line had

segregated maintenance areas that controlled contamination when individual equipment pieces needed attention. The new B-Line went into operation at the end of April 1959.[77]
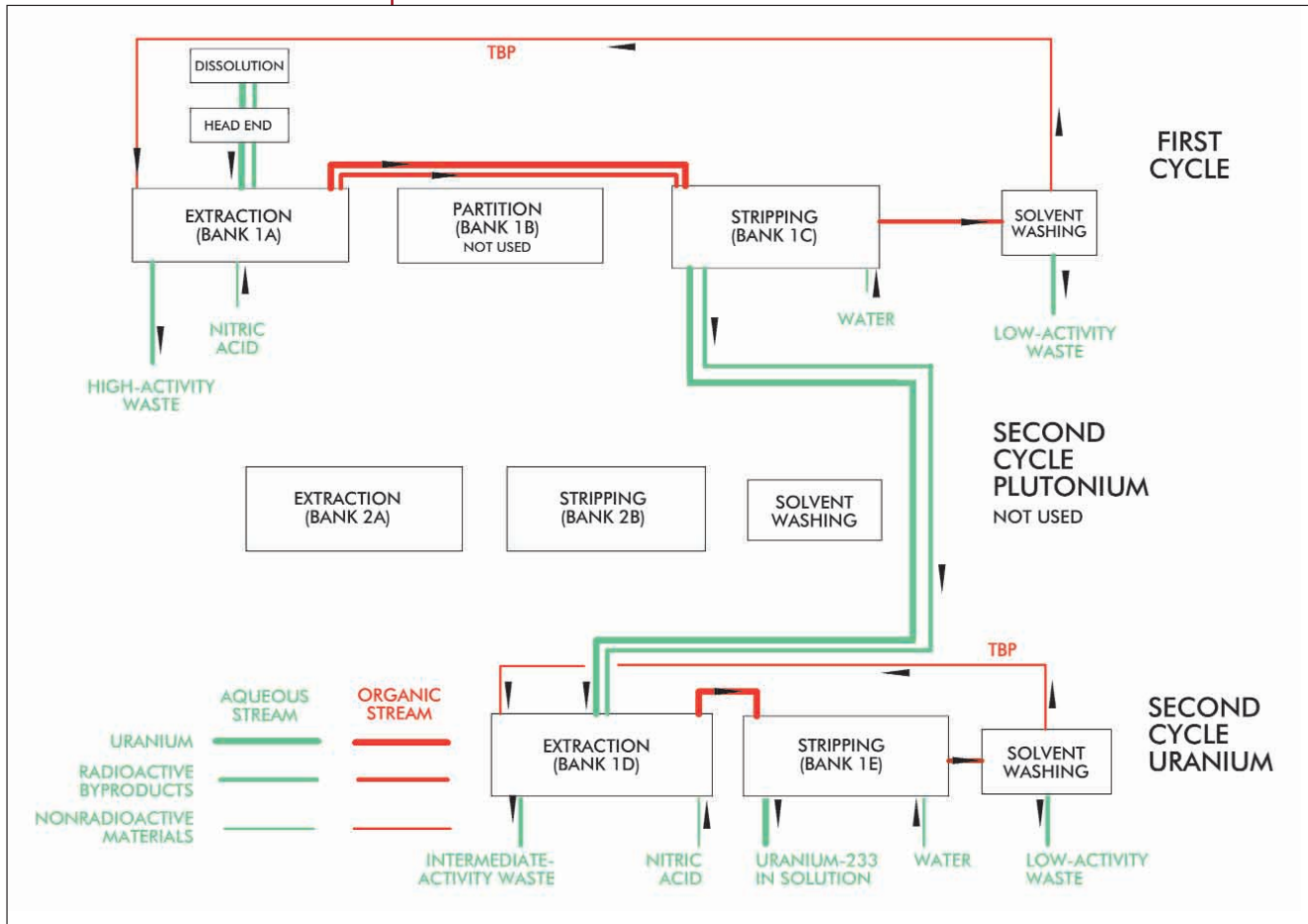
The HM process was similar to the Purex process except that no second–cycle plutonium steps were required. Source: Adapted from D. G. Karraker, *Solvent Extraction of Enriched Uranium in Conventional Purex Equipment*, Document DP-481 (Aiken, South Carolina: Savannah River Laboratory, June 1960), 5.

H Area, Processing Enriched Uranium As soon as the F Area canyon was back in operation, the H Area canyon was shut down for conversion to processing enriched uranium. The new process drew from processes worked out at Oak Ridge and elsewhere, but still used TBP and was essentially a variation on Purex, except that no plutonium was extracted. The name HM process, as it was called, was probably derived from "H Modified." The conversion was only made possible by the upgrade in F Area to a level of throughput sufficient to process enough plutonium to meet Atomic Energy Commission schedules for production. If F Area had not been able to meet production schedules alone, the construction of a new facility for the separation and purification of the uranium-235 reactor components would have been necessary. Operations in H canyon were halted in February 1959 for the modifications, which took only a few months. The canyon began operations again in May, and in general, production was satisfactory.[78]

Separations Diversification In 1959, the Savannah River mission was expanded to include the production of plutonium-238, as a power source for use in space vehicles. The program entailed first, the separation of neptunium-237 (neptunium was a byproduct of

plutonium production that prior to this had been sent to waste storage), then its fabrication into reactor targets, and irradiation to plutonium-238. The plutonium-238 was purified and initially shipped offsite, then later was converted to a solid and formed into heat sources at Savannah River. The primary recovery column was installed in F Canyon to absorb neptunium from the waste stream. The column contained a resin that absorbed both neptunium and any plutonium-239 that had followed the waste stream.[79]

Since the H Canyon had been converted to process only uranium, the second-cycle plutonium equipment was no longer being used. This was converted to decontaminate neptunium. After being partitioned from the enriched uranium in the first cycle extraction step, the neptunium was then sent to the equipment originally installed for the second-plutonium-cycle purification, where it was decontaminated with a TBP-based process. New equipment was also installed to recover neptunium and plutonium-238 from irradiated neptunium reactor targets.[80]

Much of the equipment was mounted on steel structures called "frames," each of which could be placed as a unit into a canyon module. One frame was installed in the F Canyon to purify neptunium from the primary recovery column, and two were placed in the H Canyon for purification of the neptunium from the second cycle and all processing of the irradiated neptunium targets. The first irradiated neptunium targets were processed in the H Area frames in March 1961. The first facility to convert neptunium to a solid was installed in the H Area B-Line by the end of 1961. The oxide produced in the B-Line was fabricated into reactor components in a facility in F Area that had been converted to this purpose in 1960.[81] In 1963, the Plutonium Fabrication Facility was constructed in the H Area B-Line to convert the plutonium-238 into an oxide, and produce heat sources onsite for the National Aeronautics and Space Administration, a continuing activity there for the next two decades.[82]

Separations programs involving other elements were undertaken in both F and H Canyons between 1961 and approximately 1975. These involved the recovery and purification of several isotopes of uranium, plutonium, americium, curium, europium, and other elements, primarily for research purposes. Major programs included campaigns to recover uranium-233, beginning in March 1964; Thorex campaigns for the recovery of thorium along with uranium-233, beginning in September 1965; and a variety of projects related to the production of transplutonium elements, beginning in 1962. That year, cabinets and equipment in Building 235 were decontaminated in preparation for the fabrication of plutonium-242 targets for irradiation to create transplutonium isotopes. The following year, a glove box line was installed in the building, for the manufacture of plutonium–aluminum billets with higher than normal content of plutonium-240. In 1965, the Curium-I campaign began in the F Canyon and B-Line, recovering plutonium-240, americium-243, and curium-244. There were also four programs to recover plutonium, that had a higher than normal content of plutonium-240 in the F Canyon, to be fabricated into billets in 235-F for the Curium-II campaign. A transplutonium campaign in the H Canyon and B-Line ran in late 1964 and early 1965,

E. B. Jones and Frank Loudermilk operating glove boxes on F Area's Np Line, 1978. Courtesy of SRS Archives, negative 27204-54.

recovering plutonium-241, -242, americium-243, and curium-244. These were converted to oxides in the B-Line facilities, and the highest-quality plutonium-242 was shipped to Oak Ridge for irradiation in their High Flux Irradiation Reactor.[83]

Receiving Basin for Offsite Fuels (RBOF), 1963. Courtesy of SRS Archives, negative DPSTF 1-07531.
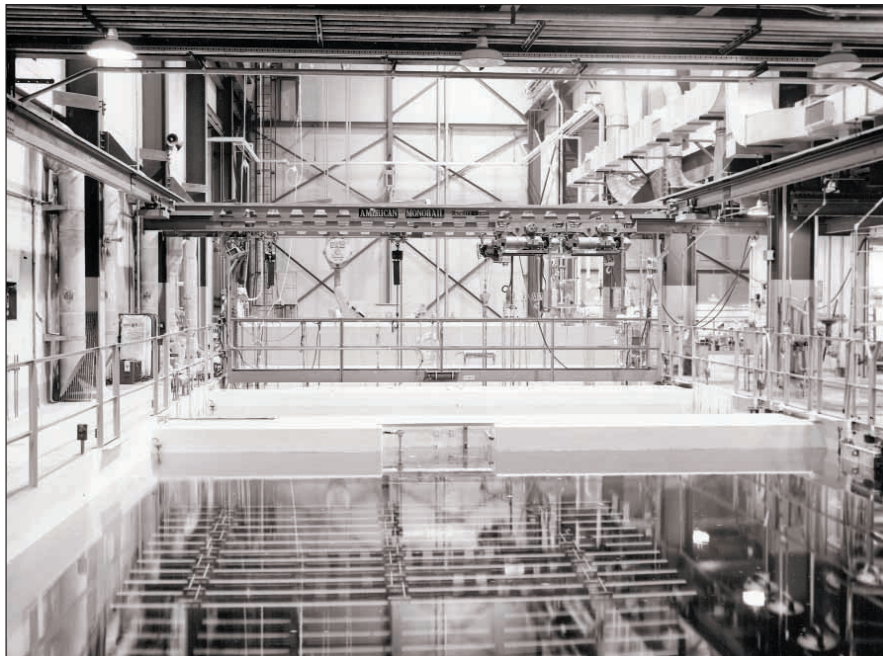
Beginning in 1960, SRP played an increasing role in reprocessing uranium used as fuel in reactors at other sites. Much of this activity arose from the "Atoms for Peace" plan initiated by President Eisenhower in 1953…. Under the program, uranium was made available from AEC stocks for use as fuel in experimental power reactors and for research reactors at universities and AEC laboratories. A general condition imposed was that the uranium should come back to the AEC when no longer needed or for reprocessing…. SRP was designated as the principal recipient of these experimental fuel elements, which were diverse in dimensions, types of cladding and nature of the fuel cores. To handle these, a new facility, the Receiving Basin for Offsite Fuels (RBOF), was built.[84]

Another way that operations diversified in the separations areas was with the storage and processing of offsite reactor elements. In 1961, construction began on the Receiving Basin for Offsite Fuels located in H Area. In 1964, Savannah River was authorized to begin receiving and processing assemblies from other sites.[85] The plant began receiving uranium-235 fuel from universities and other countries that year. These materials remained in storage until they could be processed in the H and F Canyons.

TRITIUM OPERATIONS

The F Area tritium facility went into operation in October 1955. As operating experience was gained, throughput quickly increased. By January 1956, the amount of material being placed in the furnace for a single melt had been raised to five times design specifications, causing only slight difficulties in the operation of the diffusion column. The throughput for the column was more than doubled during the initial months. Revisions to the F Area equipment in the fall of 1956 approximately doubled the capacity of tritium processing there. But the operations history of 232-F was short—the final charge was processed on October 6, 1958.[86] The new tritium facility in the H Area had made 232-F superfluous. Tritium demands waxed and waned, but at the end of 1955 demand was expected to remain high:

> The original purpose [of the Savannah River facilities] was the production of plutonium, together with the maximum tritium producible with natural uranium as the fuel. Almost immediately, emphasis shifted to maximum plutonium production. Soon interest in tritium revived and about two years ago, it appeared that the plant would by now be primarily a tritium producer. Again, as a result of new information, tritium dropped out of the picture. Instead, it was believed that U-233 producible from thorium, might be the major product. This interest waned and although some U-233 has been produced, it is no longer in the production forecast. Instead, interest in tritium has revived more bullishly than ever before and it is again estimated that the plant capacity will be largely assigned to this product in 1958. It is our belief that this time, tritium is in the production program to stay, but at what level, time alone will tell.[87]

H Area's New Tritium Facility By the end of 1955, new appropriations had been made to cover resumption of the installation of two process lines in the H Area tritium facility, and by late 1956, the work there was considered to be urgent. During 1957, construction of the second line was begun. The first line operated throughout 1958, then was shut down in December. The second line had begun operating in August, and by December its capacity was proven to be sufficient to meet production requirements of the time.[88]

Construction of the tritium packaging facility began in April 1956, and in August 1957, the building was turned over to operations. Many problems, especially with leaks and reservoir stems, had to be overcome, but by the end of the year operations were encountering no major problems. The completion of this facility allowed the tritium to be loaded in the actual weapons components rather than shipped to another site for that procedure.[89]

The H Area tritium facility, just after completion. No equipment was installed in the building, when first completed. After initial experience was gained in the F Area facility, improved equipment and processes here would make the F Area facility obsolete. Courtesy of SRS Archives, negative 2-762-12.

[I]n 1957, a new task was assigned to SRP—the loading of tritium into 'reservoirs' that would be actual components of thermonuclear weapons. This was the closest SRP ever came to justifying the name widely applied to the plant by the local population: 'The Bomb Plant'![90]

Savannah River began receiving reservoirs from thermonuclear warheads in August 1958. The tritium was discharged from the reservoirs, and fed to the process stream to be purified, primarily for the removal of helium-3. At this time, the reservoirs were not reusable, so they were sent offsite as waste, an expensive necessity because the reservoirs were costly to produce. In 1969, Savannah River would bring on line an important new facility in H Area, the Reclamation Building, that would allow reservoirs of various modified designs to be recycled. An addition to H Area's Manufacturing Building was begun in 1960, in which was installed a third process line that could handle the long tubular elements, then being irradiated in the reactors for the production of tritium. The line went into operation in September of the following year. In 1964, construction began on the Helium Recovery Building, where helium-3 was recovered and returned reservoirs were tested. The building went into operation in 1965.[91]

At the end of this period, tritium production was at an all-time high and expected to increase. "A record number of tritium boosters were loaded and shipped during 1965. SRP has the only facilities in the AEC for loading the critically important tritium boosters for nuclear weapons. Increased facilities at SRP are under way and will be in production in 1966."[92]

1962, Savannah River provided special tritium loadings for a nuclear test that shows the quick turnaround capabilities of the tritium facility. The orders for the specially loaded reservoirs were received only 72 hours before the test was to take place; the reservoirs were delivered on schedule.

Source: Orientation to Board of Directors—12/17/1962, Document Number DPW-71-170-3, December 17, 1962, Acc. 1957, Series IV, Box 48, Folder 17, 1, Hagley.

WASTE

The types of waste generated at Savannah River could be generally divided into liquid and solid wastes, and broadly classified as high-level, low-level, and transuranic waste. Liquid wastes comprised the majority by volume and radioactivity. These were stored in large tanks in the Separations Areas. Solid wastes included contaminated clothing, process and experimental equipment, some contaminated materials from offsite, and the like. These have been stored in the site burial grounds and most are classified as low-level and transuranic wastes, and have long half-lives.
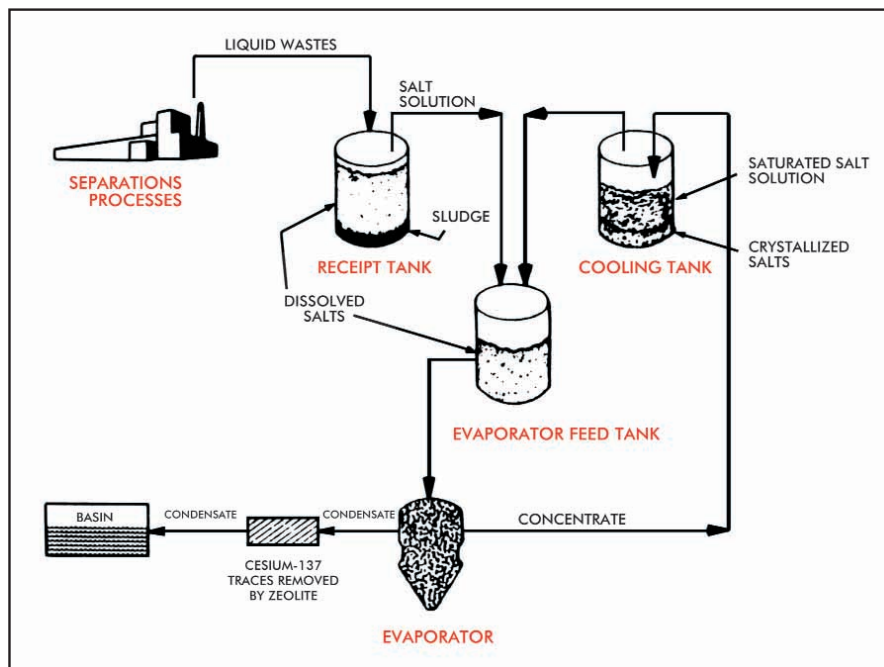
Wastes Defined

High-level wastes are defined, as the term implies, by the level of their radioactivity. Nearly all the radioactivity of these wastes is generated by the decay of short-lived radioactive products. These are also called high-heat wastes because they give off heat at a rate of between 0.5 and 5 Btu per hour per gallon. Low-level wastes are generally less than one percent as active as high-level wastes, but are still too radioactive to be released to the environment. Transuranic waste is a special type of waste that primarily gives off alpha radiation. These wastes are kept separate because they contain isotopes of elements heavier than uranium that may need to be retrieved in the future.

Source: Claude B. Goodlett, Evaporation and Storage of Liquid Radioactive Waste, in *50 Years of Excellence, 207; and An Evaluation of the Concept of Storing Radioactive Wastes in Bedrock Below the Savannah River Plant Site* (Washington, DC: National Academy of Sciences, 1972), 55.

Liquid radioactive wastes were first sent to a receipt, or aging, tank, where solids were allowed to settle and short-lived fission products to decay. In the beginning years, this was about all the activity in the waste areas. As more was learned about the behavior of the wastes, steps were taken to reduce volume. Beginning in 1960, the clear solution in the waste tanks was sent to evaporators to be concentrated, greatly reducing the volume of waste in storage at Savannah River. Source: Adapted from *Management of Radioactive Waste at the Savannah River Plant* (Washington, DC: Department of Energy, April 1976), 7.

DESIGN AND CONSTRUCTION

Originally, a single waste tank group was to serve both Separations Areas, but transfer-piping requirements made that option impractical.[93] Three important factors influenced the location of the tanks: proximity to the canyon buildings, elevation (for gravity flow to the tanks), and topography. The tanks needed to be close to the canyons, yet in areas that would allow room for more tanks to be installed in the future. Use of gravity flow meant that intervening terrain between the canyons and the tanks needed to be economical to excavate to provide the proper slope for the piping. The flow of leaks from the tank area was also considered from the standpoints of both operations and environmental safety.

> [P]erhaps most important, it was desirable to so place the tanks that any contaminated leakage would seep, into a stream flowing into the river below the plant main pump house intakes. Actually, the design of the tanks made dangerous leaks highly improbable but the remote possibility of a catastrophe was taken into consideration in their location. In such an event, any released wastes will flow into Four Mile Creek and into the river down stream from the pump houses.[94]

The tanks were designed jointly by Blaw-Knox and Du Pont, modeled on the World War II-era tanks at Hanford. The requirement at Savannah River that the tanks be blast-resistant and the higher radioactivity of the solutions to be stored at Savannah River, as well as geologic and groundwater conditions, determined the nature of the modifications to the Hanford tanks.[95]

The storage of liquid waste in these underground tanks is only regarded as a semi-permanent storage since the ever present hazard of a large earthquake could be a major disaster. Incorporation of the fission products in an unleachable concrete has been considered as one method of permanent storage…. Considerable development will be required, however, in order to make an unleachable concrete.[96]

An extensive study to determine the most practical means of meeting design requirements determined that the cylindrical tanks, each with a capacity of hundreds of thousands of gallons, should be encased in concrete. The F Area originally had more tanks than H Area; this disparity resulted from their individual development history. H Area's complement of tanks would be doubled in 1955. Each tank was buried after being set in a "saucer" designed to collect potential leaks. Squat in configuration, the tanks were roughly three times wider than their height. Interior columns were built to support the tank roof. Half the tanks in each area initially had cooling coils (intended for storage of high-level wastes, while the non-cooled tanks were for low-level wastes). In 1955, all tanks were equipped with cooling coils.[97] These tanks were considered to be sufficient to hold the waste produced during the first six years of operation. F Area had more tanks because that area was expected to see more operations activity and because wastes from the plant's laboratories were to be stored there also. Excavation for the F Area waste tanks began in June 1951, and the first slab was poured in August. The tanks were handed over to operations, beginning in the summer of 1954. In the H Area, excavation began in early 1952, and operations began accepting the tanks in early 1955.[98]

In addition to the liquid wastes, provision was needed for the safe storage of solid waste. These ranged from irradiated aluminum housing tubes used in reactor assemblies to contaminated canyon equipment, protective clothing, and instrumentation. A large enclosed burial ground was established for this purpose in proximity to the Separations areas.[99]
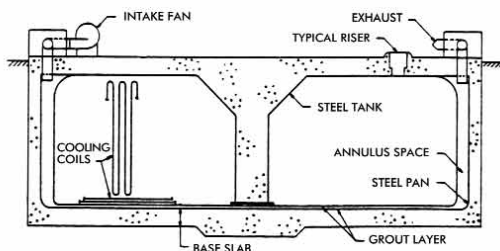

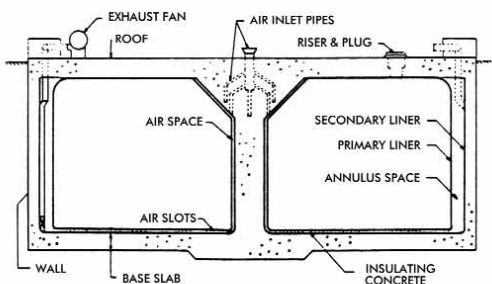F Area Type I Tanks. Courtesy of SRS Archives, negative 6098-11.

H Area Tank Farm, 1980. Courtesy of SRS Archives, negative DPSPF 30174-1.

Waste Tank Types and Chronology
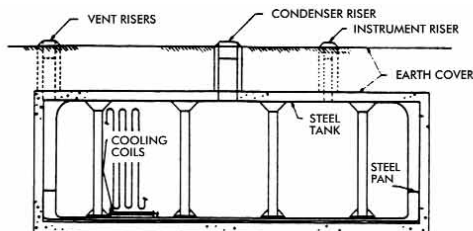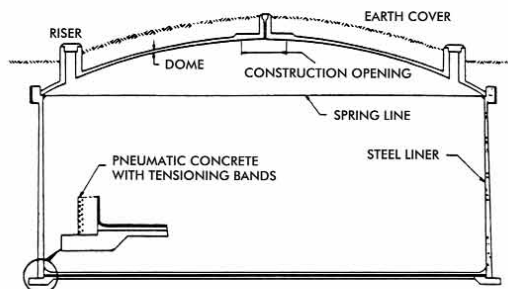
The first liquid waste storage tanks at Savannah River became known as Type I tanks. One of the most critical aspects of construction was the care that had to be taken in making and inspecting the welds of the plates that comprised the tanks. The Pittsburgh Testing Laboratory spent nearly a year and a half x-raying welds to assess quality. Between February 1952 and August 1953, approximately 50,000 feet of welded seams were checked by the laboratory.

Type II liquid-waste storage tanks were constructed in the H Area. The modified design was prompted by construction experience gained building the first tanks, by new data concerning waste behavior from Hanford, and from research at the Savannah River Laboratory.

The Type IV tanks were more economical than Type I and II. They were used to store wastes that generated less heat. These tanks were simpler than the early types, and so were cheaper to design and build. Source: *An Evaluation of the Concept of Storing Radioactive Wastes in Bedrock Below the Savannah River Plant Site* (Washington, DC: National Academy of Sciences, 1972), 56–57.

OPERATIONS

The first radioactive waste was sent to the tanks soon after 221-F began operating. These wastes were adjusted with sodium hydroxide to slightly alkaline pH levels so they would be less corrosive. The alklaine conditions precipitated radioactive elements out of the solution to form a sludge on the tank bottoms. The radioactive element remaining in the solution was primarily cesium.[100] The sludge could later be stored permanently in a more stable form, but it would be several decades before this would actually be done.

As projected production schedules increased for H Area, a need for four more tanks was seen almost immediately. Designated Type II tanks, these were slightly larger than the Type I units. The design was based on reevaluations of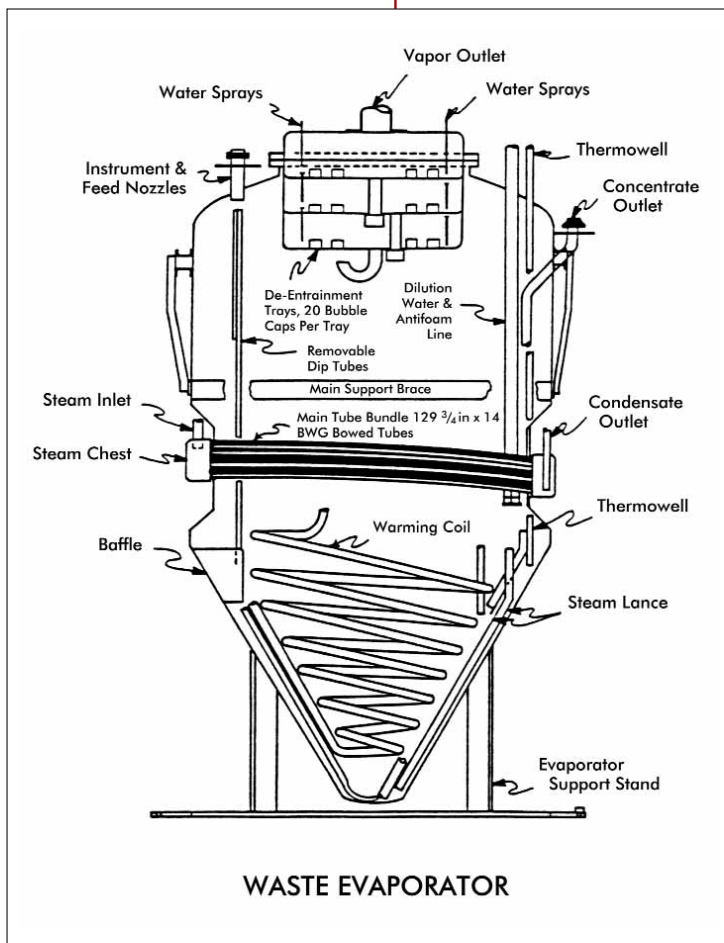 the economies of construction, experience building the Type I tanks, and new data from Hanford's Redox operations and the Savannah River Laboratory. The Type II tanks were designed for sludge of a higher temperature, the tank bottoms were set above groundwater level, and the upper extent of the liquid in storage was to remain at or below grade. Only a single center column was used for support to allow the tank bottom to expand and contract more freely. Like the Type I tanks, these also had a five-foot-high catch pan and were enclosed in concrete.[101]

Complete filling of the first waste tank by June 1955 encouraged efforts to reduce the volume of liquid wastes.[102] Soon, treatments in the waste areas began significantly reducing the volume. High-activity waste evaporators were installed first in F Area in 1960, then in H Area in 1963 to concentrate wastes, and a system of aging and concentrating the liquid was worked out. The process involved storing high-heat waste in a cooled tank until fission products with shorter half-lives settled out as sludge and decayed. The sludge was to be converted to a stable solid form when an appropriate process for doing so was developed. After sufficient aging, the only important radioactive component of the liquid was the long-lived and relatively cool cesium-137. This liquid could be concentrated in the evaporators. Single-wall Type IV tanks were designed without cooling coils for the storage of the aged liquid. Four tanks of this type were constructed in F Area in 1958, and four more were built in H Area in 1962. Although su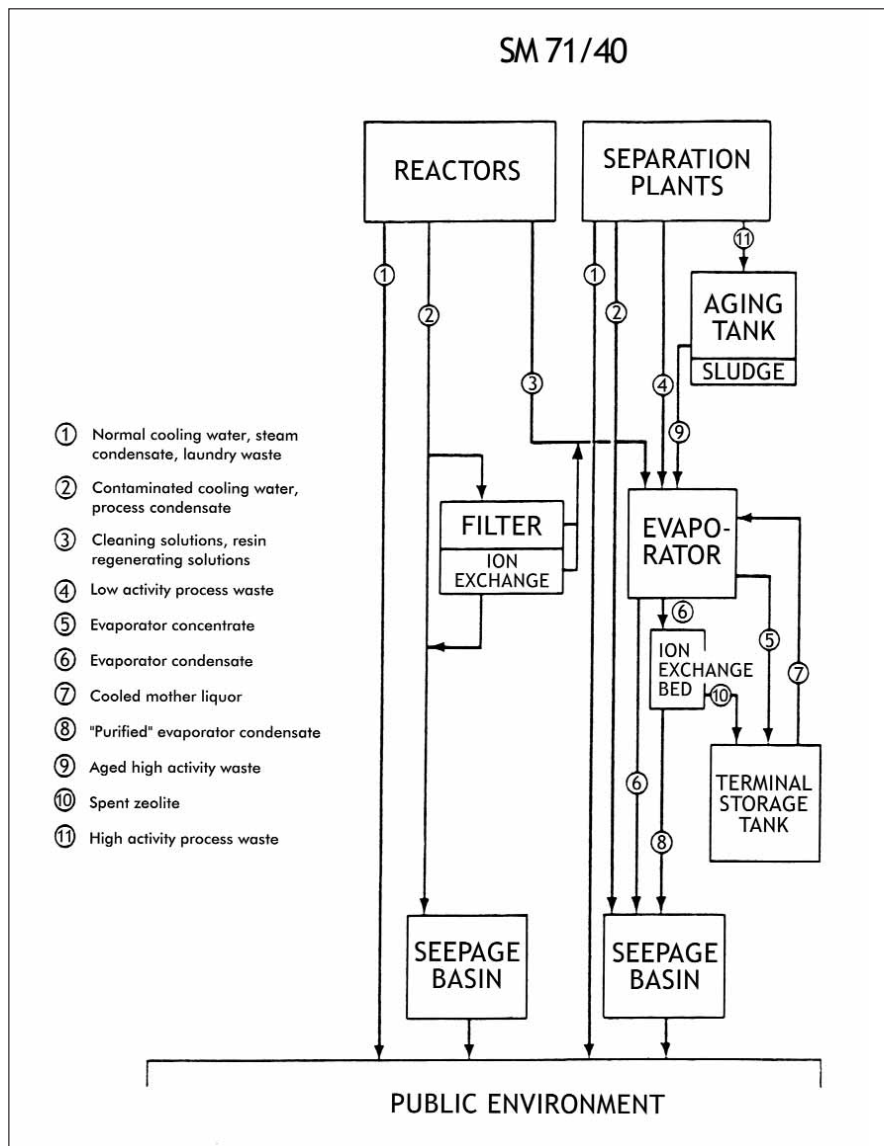ch tanks seemed justifiable at the time, leaks in some of the other tanks showed that the Type IV tanks did not offer enough protection from potential leakage to warrant expanded use, so no more of these were built. None of the Type IV tanks, however, has leaked.[103]

Several of the waste tanks began leaking shortly after operations began. A Type I tank in the H Area, the first to have been filled there, began leaking high-activity waste during the summer of 1957. By the end of October it had lost approximately 16,000 gallons.

WASTE EVAPORATOR

Labels: Vapor Outlet; Water Sprays; Water Sprays; Thermowell; Instrument & Feed Nozzles; Concentrate Outlet; De-Entrainment Trays, 20 Bubble Caps Per Tray; Dilution Water & Antifoam Line; Removable Dip Tubes; Main Support Brace; Main Tube Bundle 129 ¾ in x 14 BWG Bowed Tubes; Steam Inlet; Condensate Outlet; Steam Chest; Thermowell; Warming Coil; Baffle; Steam Lance; Evaporator Support Stand

Cross-section of Savannah River waste evaporator. Source: J. E. Haywood and T. H. Killian, Overview of Savannah River Plant Waste Management Operations, in *Waste Management '87*, ed. Roy G. Post, vol. 2 (Tucson: University of Arizona, 1987), 52.

Leaks in a Type II tank in the H Area were discovered in May 1959, and a third tank (Type I) was discovered to be leaking two months later. One of the worst incidents of leakage

SM 71/40

REACTORS

SEPARATION PLANTS

AGING TANK

SLUDGE

① Normal cooling water, steam condensate, laundry waste

② Contaminated cooling water, process condensate

③ Cleaning solutions, resin regenerating solutions

④ Low activity process waste

⑤ Evaporator concentrate

⑥ Evaporator condensate

⑦ Cooled mother liquor

⑧ "Purified" evaporator condensate

⑨ Aged high activity waste

⑩ Spent zeolite

⑪ High activity process waste

FILTER

ION EXCHANGE

EVAPO-RATOR

ION EXCHANGE BED

TERMINAL STORAGE TANK

SEEPAGE BASIN

SEEPAGE BASIN

PUBLIC ENVIRONMENT

Shown are the routes that waste, produced by operations at Savannah River, followed to the environment and to storage tanks during the early years of operation. Source: R. M. Girdler, Handling of Low- and Medium-Level Liquid Waste at the Savannah River Plant, in *Practices in the Treatment of Low- and Intermediate-Level Radioactive Wastes, Proceedings of the Symposium on Practices in the Treatment of Low- and Intermediate-Level Radioactive Wastes* (Vienna: International Atomic Energy Agency, 1966), 481.

began about November 1959, in another H Area Type II tank. Leakage from this tank increased dramatically to about three and one-half gallons per minute in the fall of 1960; the flow—all of which came from cracks near welds—was lessened by removing some of the liquid from the tank to lower the pressure.[104]

These four leaking tanks in H Area (no leaks had yet been detected in the F Area) prompted Du Pont's Atomic Energy Division to request an extensive investigation of the causes. The resulting report found that stress corrosion cracking caused at least one of the tanks to leak and probably caused all the leaks; and determined that repair of the tanks was not feasible. A portion of the tank experiencing the worst leaks was cut out for test-

(Right) Periscopes were used to inspect the walls of waste tanks for leaks. Source: R. M. Girdler, *Leaks in Radioactive-Waste Tanks*, Document DP-990 (Aiken, South Carolina: Savannah River Laboratory, December 1965), 17. Courtesy of SRS Archives, negative 7555-1.

(Below) Waste Tank Leak Site. Photograph taken from the annular cavity between the outer tank wall and the inner concrete enclosure wall. Source: *Waste Management Operations,* Document ERDA-1537 (Aiken, South Carolina: Savannah River Plant, September 1977), II-107–II-108. Courtesy of SRS Archives, negative 23205-1.

ing, the results of which indicated the hazardous material process wastes held in that tank were particularly aggressive at initiating stress-corrosion cracking. It was suggested that all future tanks be fully stressed relieved during construction by heating to 1100º Fahrenheit. All of these leaks eventually sealed themselves through the deposition of solids in the small openings, a process aided by the circulation of heated air in the space between the tank wall and concrete enclosure to encourage evaporation and the accumulation of the solids.[105]
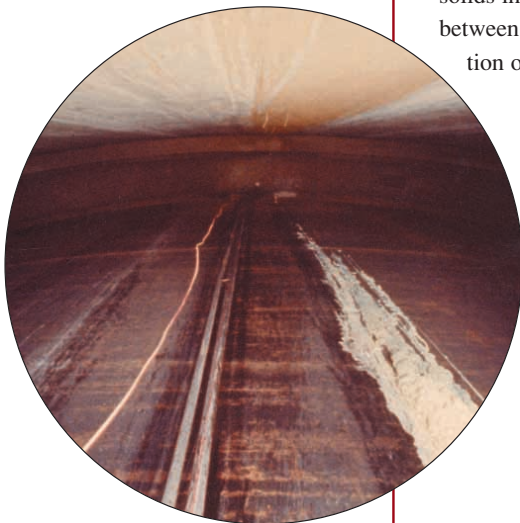
> When the supernate from stored waste is evaporated, the residue is thereby saturated with salts at a temperature of about 100° C above ambient, and upon encountering a cool surface such as the wall of a tank, it immediately deposits a layer of salt. Thus, any tank that has received evaporator tailings in amount[s] sufficient to bring the salt content above saturation at ambient temperature (and we propose to put all tanks in this condition) is self-sealing against cracks. The sealing action is simply a matter of change in solubility with temperature, there being necessarily a temperature differential between the interior and the exterior of the tank. The sealing action has no relation to the composition of material outside the wall…. Thus, the evaporated waste, partially solidified in tanks, appears to be immobilized.[106]

Very low-level liquid waste was sent to seepage basins and allowed to soak into the ground. By design, seepage basins were about ten feet above the natural water table, located as far as practical from streams, and constructed in soil permeable enough to allow adequate seepage, but dense enough to give radioactive elements time to decay. The soil also needed to have good absorptive characteristics for radioactive isotopes, an attribute aided by higher clay content. Liquid from the seepage basins was expected to take several

years to reach the local river systems, and most of the radioactive isotopes would have decayed by then.[107]

The original burial ground, now known as the Old Burial Ground, was used from 1952 until 1974. During those years, solid waste was placed in approximately 160 trench-

SM 71/40
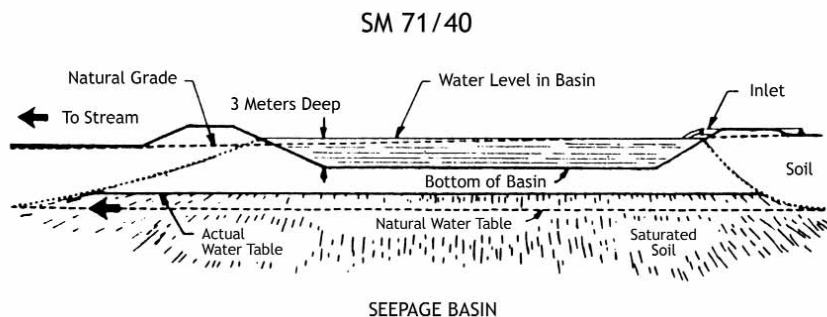
SEEPAGE BASIN

Cross-section of a typical seepage basin at Savannah River. Source: Robert M. Girdler, Handling of Low- and Medium-Level Liquid Waste at the Savannah River Plant, in *Practices in the Treatment of Low- and Intermediate-Level Radioactive Wastes* (Vienna: International Atomic Energy Agency, 1966), 483.

es, segregated according to type and level of activity. In addition to being radioactive, some burial ground wastes contained mercury, lead, cadmium, solvents, and other hazardous substances. Up until 1965, transuranic waste was placed in bags and boxes and buried like other solid contaminated wastes. After 1965 these wastes were segregated by level of activity, and some were placed in retrievable concrete containers. Savannah River was one of the first sites in the weapons complex to store these wastes in a way that they could be recovered—the federal government did not define procedures specifically for

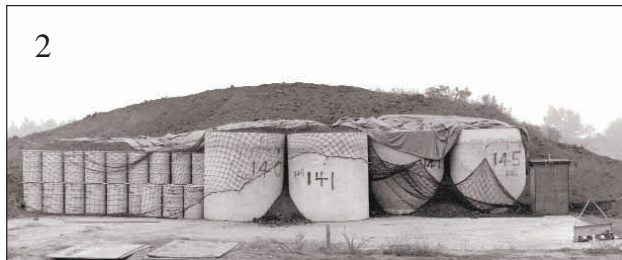H-Area Seepage Basin. Courtesy of SRS Archives, negative 36633-6.

handling transuranic waste until about ten years later. Seepage tests were conducted, during the early years of operation, to determine rates of the spread of contamination from the materials that would be buried there, and routine monitoring for contamination has been ongoing part of operations.[108]

Diluted TBP that had degraded during operations and was no longer useable, was fairly free of radioactivity, so this was sent to the burial ground instead of the waste tanks. There, it was held temporarily in 18 storage tanks (installed between 1955 and 1962), then

BURIAL GROUNDS

1. Low-level radioactive wastes were placed in plastic or cardboard boxes and buried in trenches. Courtesy of SRS Archives, negative DPSTF – 1-11937-8. 2. After 1965, some wastes were segregated by level of activity, and some were placed in retrievable concrete containers, 1976. Courtesy of SRS Archives, negative DPSTF-1 13093-10. 3. Wastes in the burial ground were segregated according to the type of waste and level of activity. Courtesy of SRS Archives, negative DPSPF 28321-1. (Map) The Old Burial Ground is the lower area shown in drawing. Source: *Waste Management Operations*, Document ERDA-1537 (Aiken, South Carolina: Savannah River Plant, September 1977), II-119.
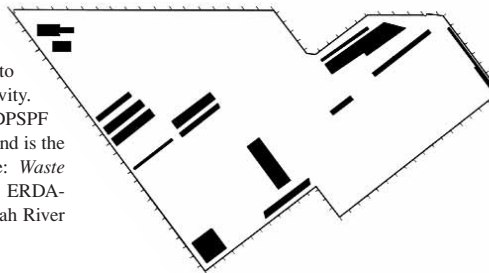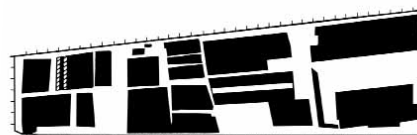
burned in a large open pan, dispersing combustion products to the atmosphere and leaving only residues to be buried. Radioactivity released to the atmosphere by this practice was minimal; the main radioactive contaminant in the TBP solution was ruthenium, which remained in the burn pan as residue.[109]

Seeking a Means of Permanent Storage As mentioned previously, the storage of high-level waste in steel tanks was considered only a temporary solution to handling process wastes at Savannah River. More permanent solutions were being sought even during initial design and construction. Conversion to a solid of some type was the primary approach to permanent storage. Investigations ranged from pumping solution underground to conversion to solid cakes that could be dumped into the oceans.[110]

One early potential solution that received a great deal of attention was storage in deep underground vaults beneath the plant. A mine shaft over 1000 feet deep was to be dug, then storage chambers would be excavated into granite bedrock underlying the area. Consideration was given to pumping wastes directly into these tunnels. By 1957, the idea was temporarily abandoned because of findings related to the permeability of the formations beneath the plant.[111]

The bedrock storage idea was revived in the late 1950s. A proposal was submitted to the Atomic Energy Commission in 1958, and brought to the attention of the National Academy of Sciences in 1960. The academy recommended that test borings be taken to see if the proposal was feasible, and this work began in 1961. Investigations continued for several years, and the concept was not abandoned until the 1970s. One problem was that the shaft to the storage tunnels would pass through the Tuscaloosa Aquifer for several hundred feet.[112]

Another means of permanent storage was developed around the unusual properties of sulfur. Savannah River Laboratory research indicated wastes could be combined with molten sulfur, then placed in containers and allowed to solidify, creating a solid that was very resistant to leaching and possible release of radioactive materials. This process was considered to produce a product similar to glass, but at a significant savings of processing and handling costs.[113]

Vitrification, however, was the approach that was eventually adopted as the best method of stabilizing the wastes, and Savannah River's Defense Waste Processing Facility was constructed to vitrify wastes. The properties of different varieties of glass were studied at many of the Atomic Energy Commission laboratories. The most important research at Savannah River began in the 1970s, when the basic decisions and equipment designs were developed.[114]

The storage of radioactive waste in bedrock underlying the plant would have required an access shaft possibly 1500 feet deep. Source: *An Evaluation of the Concept of Storing Radioactive Wastes in Bedrock Below the Savannah River Plant Site* (Washington, DC: National Academy of Sciences, 1972), 10.